PORTO RICO AGRICULTURAL EXPERIMENT STATION
MAYAGUEZ, PORTO RICO
Under the supervision of the
UNITED STATES DEPARTMENT OF AGRICULTURE

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EXPERIMENTS WITH FERTILIZERS FOR COFFEE IN PORTO RICO

BY

T. B. McCLELLAND, Horticulturist

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CONTENTS

Coffee occupies a prominent place in the agriculture of Porto Rico by reason of the large area planted with the crop, the many people engaged in its cultivation, and the income derived from its exportation. Production per acre is generally low, however, and planters are interested in learning how to increase yields. Requests are frequently received at the station for information as to the use of chemical fertilizers for coffee. This bulletin gives the results of experiments made during a series of years at the station and elsewhere in Porto Rico to determine the effect of fertilizer on growth and yield of coffee, and covers many of the points in question.

FIELD EXPERIMENTS

SOUTH FIELD PLATS

In Porto Rico coffee is usually planted on steep slopes. Such locations are not, as a rule, suited to coffee planting for comparative purposes, since variations in topography cause a high degree of variability in growth and yield of crop. To eliminate this disturbing factor a strip of apparently level land was selected as the site for field work. The land near by slopes toward the river and furnishes what would be good drainage were it not for the nature of the soil, which is a heavy, almost impervious brown Adjuntas clay.[1] The

[1] This type of soil is described in detail in Porto Rico Sta. Bul. 14, The Red Clay Soil of Porto Rico.

land would be considered excellent for cane growing and is better than is ordinarily used for coffee.

The plats are shaded by leguminous trees, which are uniformly planted throughout and kept thinned or replanted as may be required to maintain favorable light and shadow. The trees furnish a heavy mulch of fallen leaves and twigs and, in effect, may be considered a leguminous cover crop.

Seed from a single Arabian tree of the Padang variety was planted in October, 1913, and the resulting seedlings were set in permanent place in September, 1914. They failed to thrive, however, owing to poor drainage, and many had to be replaced with others from the same nursery. Eleven replacements were made later with seedlings from a tree of the original planting. These were not included in the records of data until 1924, when eight of the trees, then 8 years old, apparently equaled companion trees in yield.

The trees were set in 40 plats of 3 trees each and spaced 6 feet apart within the plat and 9 feet between plats. Shallow ditches have run lengthwise the plats since 1919. The field was separated into 5 divisions, each of which contained a check plat, 1 plat which received a complete fertilizer—nitrogen, phosphoric acid, and potash—1 plat for each combination of 2 elements, and 1 plat for each element alone. Where 1 or 2 elements only were applied the quantity of each equaled that of the same element used in the complete fertilizer. A single definite rate of fertilization was applied to all trees within a division. Beginning on the west side of the field, each division to the east received twice as much fertilizer as the preceding, so that the most eastern or fifth division received 16 times as much fertilizer as was given the most western or first division. (See fig. 6.)

In the discussion the term "group" refers to all trees (15 trees, including 1 plat from each division) which received fertilizer identical in quality and the term "section" refers to all trees (60 trees, including 4 plats from each division) which received a particular element, such as nitrogen, either alone or in combination. The check comprised all trees failing to receive any particular element. Nitrogen is indicated by the letter N, phosphoric acid by the letter P, and potash by the letter K.

In the first division complete fertilizer was used at the rate of 1/4 pound per tree per application, in the second at the rate of 1/2 pound, in the third at the rate of 1 pound, in the fourth at the rate of 2 pounds, and in the fifth at the rate of 4 pounds per tree, the single elements and combinations of two elements being applied at the same rates as in the complete fertilizer. Applications were made semiannually, usually in December and in May.

Since November, 1917, the fertilizer has been uniformly distributed over a square 6 by 6 feet, with the tree in the center. The six applications which were made prior to that date were smaller than is noted in the diagram, because they were applied to a smaller area. They were given at a rate proportionate to the area fertilized, however, the trees being too small at first to benefit by the application later given the full area.

The basal formula used was 7 per cent nitrogen, 10.5 per cent phosphoric acid, and 14 per cent potash, thus carrying 1 part nitrogen, 1 1/2 parts phosphoric acid, and 2 parts potash. The materials used were ammonium sulphate, superphosphate, and potassium sulphate.

Quarterly measurements of height were taken over the period of most rapid stem elongation, from October, 1914, when the trees were for the most part less than 2 feet high, to October, 1917, when they averaged 6 to 7 feet high, and most of them had borne two crops of fruit. These measurements failed to show any consistent and significant differences attributable to the kind of fertilizer applied.

It has been thought that trunk diameters furnish the most accurate measurements of growth, and, consequently, the most reliable index of tree performance.[2] In November, 1924, measurements were taken of the trunk diameter at 3 inches above the base. The average trunk diameter for each plat is given in Table 1, which shows that, when the five divisions are considered as a unit, nitrogen and potash in combination, either with or without phosphoric acid, produced a very considerable increase in growth, but that nitrogen alone or in combination with phosphoric acid, but without potash, produced a growth considerably below that of the check group. Ten of the 40 plats exceeded the highest check plat, and all except 1 of these received potash and 7 received both nitrogen and potash.

TABLE 1.—*Average diameter of differently fertilized coffee tree trunks at 3 inches above base, November, 1924*

Division	Rate of fertilizer application per tree [1]	Plats receiving—							
		K	P	N	NK	PK	NP	NPK	O
	Pounds	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1	¼	2.3	2.0	2.1	3.1	2.3	2.2	2.3	2.2
2	½	2.4	2.3	2.8	2.6	2.5	2.3	2.8	2.4
3	1	2.6	2.4	2.6	2.9	2.4	2.4	3.2	2.7
4	2	2.7	2.9	2.3	3.1	2.8	2.5	2.9	2.8
5	4	3.0	2.7	1.8	3.4	3.0	1.8	3.3	2.8
Total		13.0	12.3	11.6	15.1	13.0	11.2	14.5	12.9

[1] The figures in this column represent the rates of application of complete fertilizer. The single elements and combinations of two elements were applied at the same rates as in the complete fertilizer.

Figure 1 graphically averages the trunk diameter for each plat. Considering the plats of each division in relation to their respective check plats only, it is seen that 17 of the 40 plats surpassed the checks. Of these 17, all except 2 received potash, and 10 received both nitrogen and potash. All the NPK and NK plats surpassed their checks in trunk diameter, whereas this held true for no other fertilizer combination or element when applied singly. The growth failed to show benefit from adding phosphoric acid to the NK combination. Fifteen plats fell below their respective checks in trunk diameter. Of these, 4 received nitrogen alone, 4 phosphoric acid alone, and 4 nitrogen and phosphoric acid in combination.

The injury done by nitrogen, either singly or in combination with phosphoric acid only, in very heavy applications was evident from the very poor growth made by the plats so fertilized in the fifth division. Plant growth on plats receiving identical quantities of nitrogen to which potash was added appeared in strong contrast.

[2] HEDRICK, U. P., and TUKEY, H. B., TWENTY-FIVE YEARS OF FERTILIZERS IN A NEW YORK APPLE ORCHARD. N. Y. State Agr. Expt. Sta. Bul. 516, p. 16.

As the plats were small, each point of the curves in Figure 2, showing the effect of fertilizers on growth, was determined by the average of the plats in two divisions. The stimulation to growth furnished by the NK combination is here very evident, and the depressing effect of nitrogen when heavily applied and unaccompanied by potash is equally pronounced. The curves for trunk diameter and for yield are very similar and tell practically the same story. Growth and yield are closely correlated.[3]

The trees began fruiting in 1916. The crop was very small, and counts of the cherries averaged 106 to the tree for the planting as a whole. Thirteen plats produced more than the highest check plat. Eleven of the thirteen received nitrogen singly or in combination, and the section receiving the nitrogen produced over twice as many cherries as were produced by the check section. If inference were to be drawn as to the effect of fertilizer on the very small initial

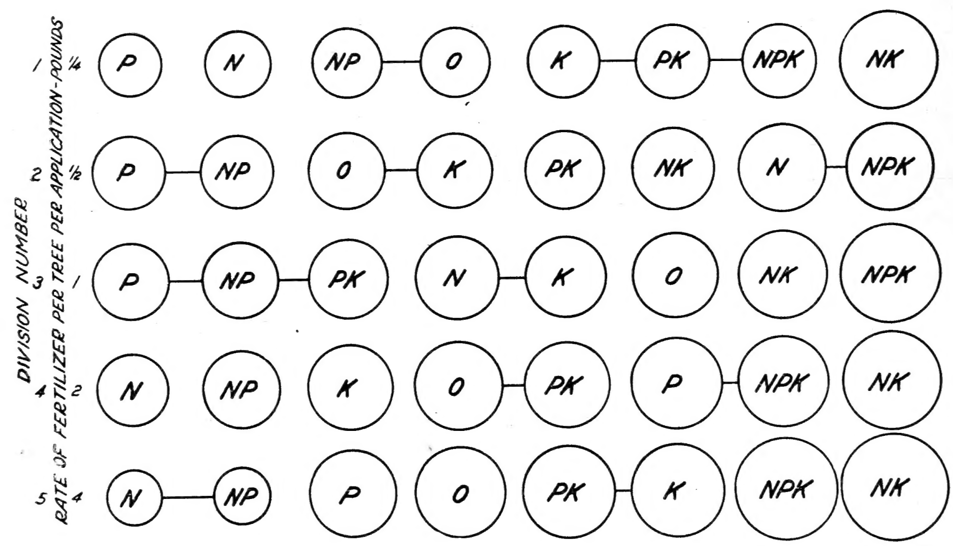

FIG. 1.—Average trunk diameter per plat in relation to the fertilizer applied, the plats of each division ranked according to trunk diameter, horizontal lines joining plats of equal rank. Key to figures, showing fertilizers applied. Symbols are combined to indicate fertilizer combinations. The fertilizer contained 7 per cent nitrogen, 10.5 per cent phosphoric acid, and 14 per cent potash

crop it would be thought that nitrogen increased early production. The freshly picked cherries of subsequent crops were weighed and the weights were recorded in grams.

The first important production was made in 1917 when the crop yielded an average of 971 grams (2 pounds 2 ounces) of cherries, which is equivalent to 5 and a fraction ounces per tree of dried coffee beans with the parchment removed. The average production per tree in 1924 was the equivalent of about 1½ pounds of dried coffee beans with the parchment removed. The yields of these two crops and for the 8-year period 1917–1924 as a unit are graphically shown in Figures 3, 4, and 5, and the data for the 8-year period are given in Table 2.

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[3] "There is a high degree of correlation between trunk circumference and yield of fruit in apple trees." WARING, J. H. THE PROBABLE VALUE OF TRUNK CIRCUMFERENCE AS AN ADJUNCT TO FRUIT YIELD IN INTERPRETING APPLE ORCHARD EXPERIMENTS. Amer. Soc. Hort. Sci. Proc., 1920, p. 179.

TABLE 2.—*Average weight of cherries per coffee tree for the 8-year period 1917–1924, from differently fertilized plats ranked in sequence of production*

Plat No.[1]	Fertilizer	Relative quantity of fertilizer applied [2]	Weight of cherries	Plat No.[1]	Fertilizer	Relative quantity of fertilizer applied [2]	Weight of cherries
			Grams				*Grams*
58	NK	16	32, 556	27	P	2	12, 294
43	NK	8	27, 239	15	PK	1	12, 102
46	NPK	8	27, 211	26	K	2	12, 064
28	N	2	26, 808	35	N	4	12, 032
36	NK	4	25, 194	25	None	0	11, 845
48	PK	8	24, 782	51	PK	16	11, 830
47	None	0	24, 028	22	PK	2	11, 447
53	NPK	16	22, 529	45	NP	8	11, 014
55	K	16	21, 692	54	None	0	10, 990
33	K	4	21, 075	11	K	1	10, 804
14	NK	1	20, 687	23	NP	2	10, 774
24	NPK	2	19, 880	16	NP	1	10, 663
44	K	8	19, 874	41	P	8	10, 333
56	P	16	17, 190	18	None	0	9, 447
37	PK	4	16, 085	13	N	1	7, 121
31	NPK	4	16, 009	38	NP	4	5, 696
21	NK	2	14, 335	12	P	1	5, 145
32	None	0	12, 943	42	N	8	3, 880
34	P	4	12, 540	57	N	16	2, 708
17	NPK	1	12, 524	52	NP	16	1, 454

[1] Seventeen trees either died or were so badly injured as to necessitate excluding from crop records. These included one tree each for the following listed plats: Division 1, NK, 1918–1924; PK, 1924; O, 1919–1924; division 2, NP, 1919–1923; N, 1918–1924; N, 1919–1924; division 3, P, 1918–1923; N, 1923; PK, 1918–1923; division 4, P, 1919–1923; P, 1921–1924; K, 1923–1924; PK, 1924; division 5, PK, 1919–1923; NPK, 1918–1923; P, 1919–1923; N, 1919–1923.

[2] Quantity applied in comparison with lowest quantity expressed as 1.

The general trend of future performance was indicated in the plats receiving the heavier applications as early as the first important crop, which was produced four years after seeding and three years after setting. Here, it appears that potash, especially when used in addition to nitrogen, was effective in increasing crop yield. This is shown much more clearly in the curves for the 1924 crop. In this crop 11 plats yielded better than the best check. These agree is one particular only. All received potash, 4 received nitrogen only in addition to potash, 1 received phosphoric acid only in addition to potash, and 3 received both nitrogen and phosphoric acid in addition to potash. Table 3 shows the 12 plats of highest yield, ranked in sequence of average production per tree.

TABLE 3.—*Showing 12 plats of highest yield, 1924, ranked in sequence of average production per tree and their fertilizer treatment*

Plat No.	Fertilizer	Relative quantity of fertilizer applied [1]	Yield of cherries per tree	Plat No.	Fertilizer	Relative quantity of fertilizer applied [1]	Yield of cherries per tree
			Grams				*Grams*
48	PK	8	9, 935	46	NPK	8	6, 421
58	NK	16	8, 524	53	NPK	16	6, 302
55	K	16	7, 713	36	NK	4	6, 271
43	NK	8	7, 415	14	NK	1	6, 038
33	K	4	6, 623	44	K	8	5, 874
24	NPK	2	6, 424	47	None	0	5, 811

[1] Quantity applied in comparison with lowest quantity expressed as 1.

In the harvests for each of the eight years 1917–1924, inclusive, the NPK group and the NK group outyielded the unfertilized group. The K group for seven of the eight years and the PK group for five years outyielded the check, whereas the P group and the NP group surpassed the check only once each and the N group did not surpass it at all. Figure 6 graphically averages the total yield per tree for the 1917–1924 period as the plats lie in the field. Each line represents the production of a kilogram of coffee cherries. In divi-

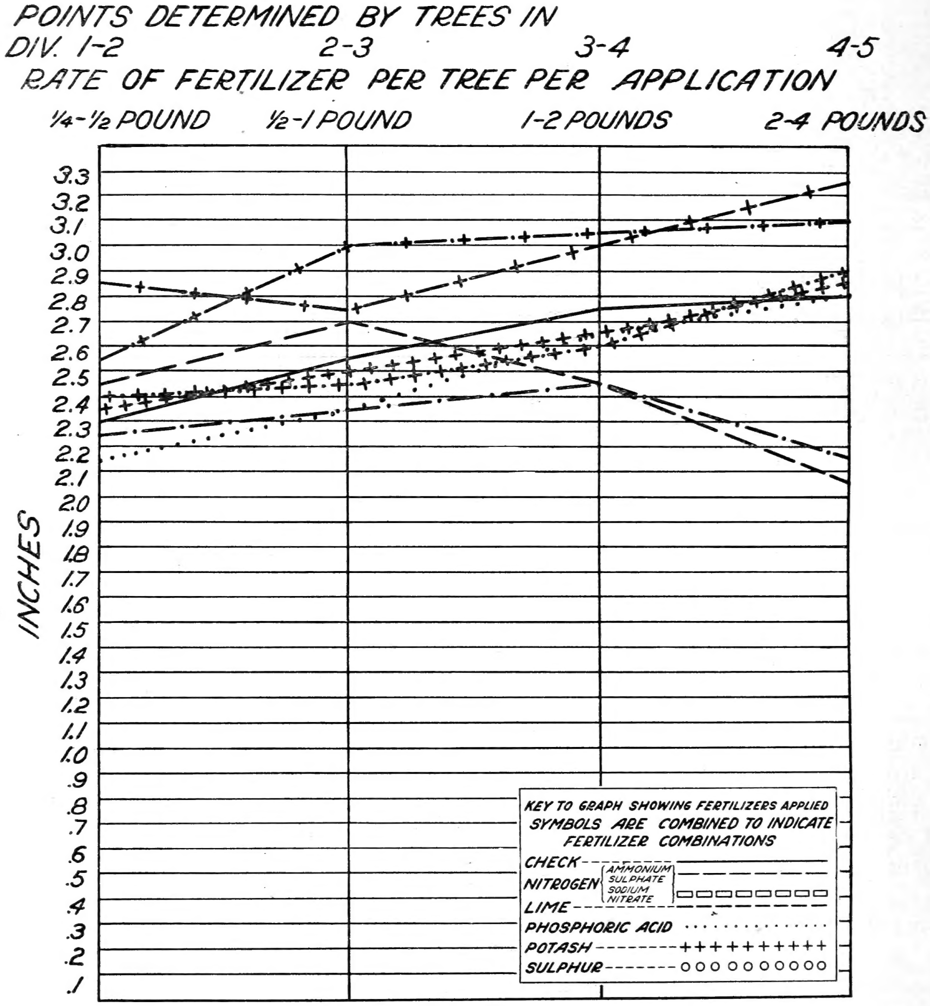
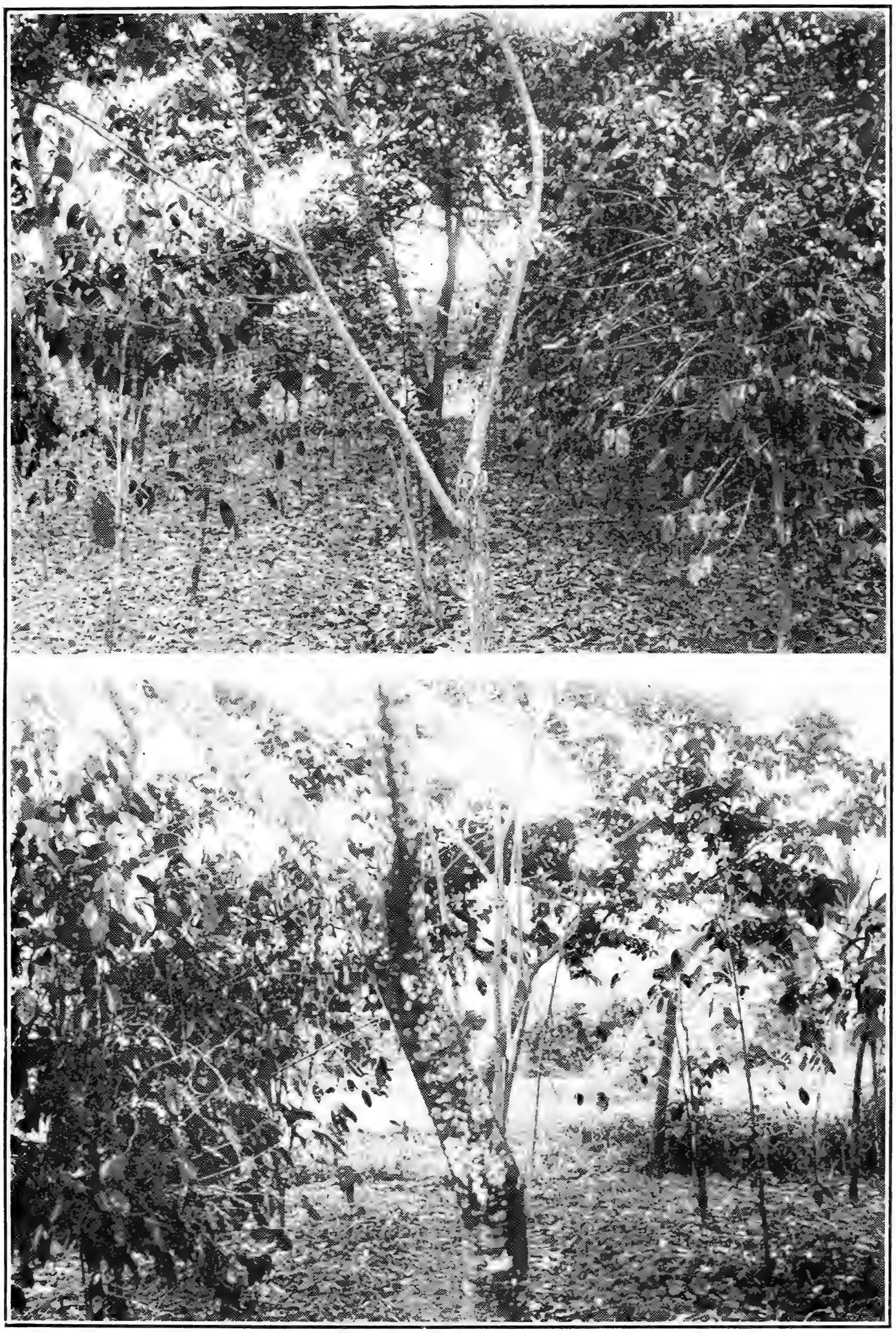


FIG. 2.—The depressing effect on growth of heavy applications of nitrogen unaccompanied by potash and the stimulating effect of the two together, as shown by tree trunk diameter measured November, 1924

sions 4 and 5 nitrogen in heavy applications and without potash very adversely affected fruiting, whereas the same quantity used in conjunction with potash proved beneficial rather than injurious. The appearance of the trees as well as their production was affected by the treatments, the plats receiving nitrogen alone in heavy applications producing only sparse foliage and poor growth in contrast with the luxuriant foliation and growth on the plats receiving nitrogen and potash in combination. (Pl. 1.)



SHOWING POOR GROWTH OF COFFEE IN SOUTH FIELD FOLLOWING HEAVY APPLICATIONS OF NITROGEN ALONE, PLAT 42, UPPER LEFT, AND PLAT 57, LOWER RIGHT; AND VIGOROUS DEVELOPMENT WHERE TO THE SAME QUANTITIES OF NITROGEN, POTASH HAS BEEN ADDED, PLAT 43, UPPER RIGHT, AND PLAT 58, LOWER LEFT

Photographed January, 1922

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The highest yield for the eight-year period was made by the NK plat in the fifth division. This plat was fertilized at the heaviest rate, receiving 4 pounds per tree per application (1 pound 6½ ounces ammonium sulphate and 1 pound 2 ounces potassium sulphate per tree per application), or 8 pounds annually of a 7:0:14 fertilizer combination. The last two yields from the plat were very high, averaging 2 pounds 15 ounces and 2 pounds 13 ounces, respectively, per tree per annum, of dried coffee beans with the parchment re-

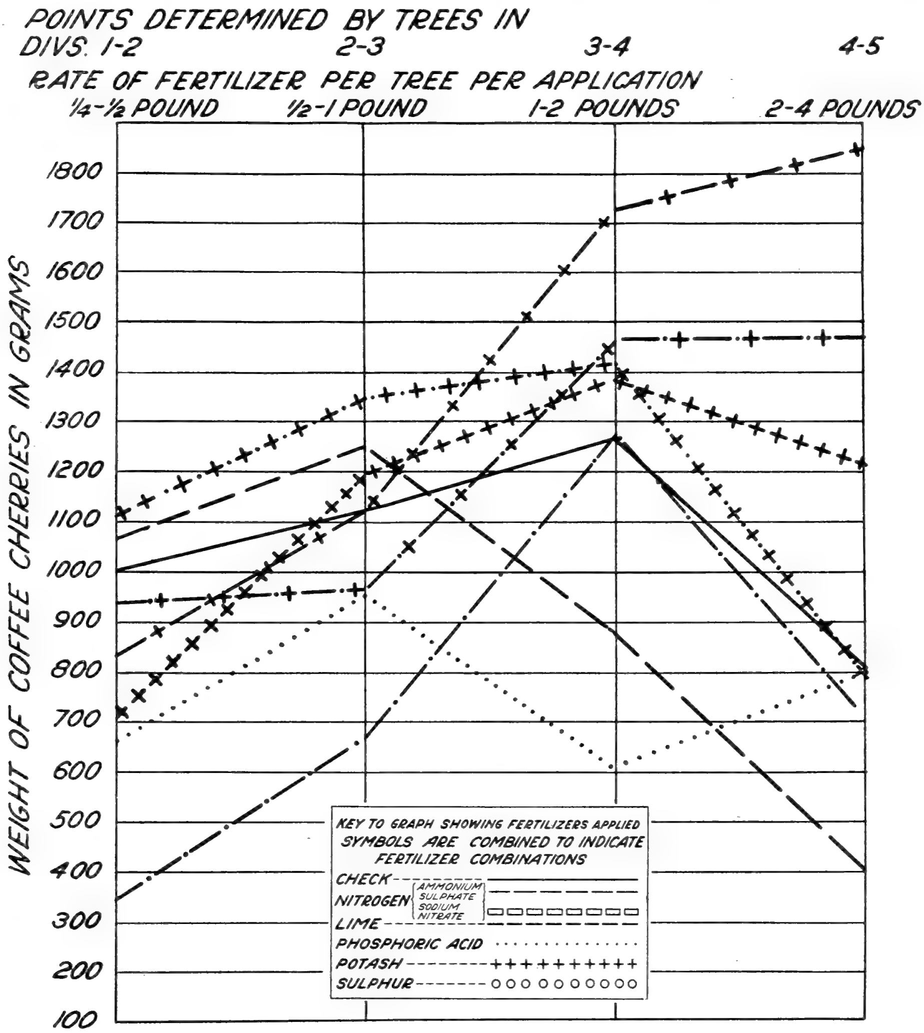

FIG. 3.—Average production per tree for the year 1917. South Field plats

moved. This plat produced nearly three times as great a yield for the eight-year period as did the check in the same division.

Contrasting all trees receiving any one element with those not receiving that element, and considering the latter section as the check, it is seen that for the 1917–1924 period as a unit the nitrogen section surpassed its check in yield by 4 per cent, the phosphoric acid section fell below its check by 17 per cent, and the potash section surpassed its check by 82 per cent. Table 4 gives the average production for the trees for the 1917–1924 period.

TABLE 4.—*Comparison of average production of trees receiving any one fertilizer element and of those failing to receive that element, South Field plats*

Year	Yield of cherries with the different fertilizer treatments					
	Nitrogen	Check	Phosphoric acid	Check	Potash	Check
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
1917	1,007	936	911	1,031	1,160	782
1918	1,564	1,168	1,308	1,419	1,812	923
1919	636	447	460	620	699	377
1920	1,164	637	897	905	1,275	498
1921	1,998	1,810	1,583	2,209	2,251	1,525
1922	1,567	1,547	1,393	1,713	2,236	811
1923	3,092	3,185	2,677	3,590	3,925	2,272
1924	4,083	4,747	4,152	4,676	5,611	3,207
Total	15,111	14,477	13,381	16,163	18,969	10,395
Percentage in respect to check	104	100	83	100	182	100

Figure 7 shows the curves for the sections.

CHANGES IN THE SOIL SOLUTION AS A RESULT OF THE FERTILIZER TREATMENTS

Examination of changes in the soil solution of the plats was made by J. O. Carrero, assistant chemist of the station. His report follows:

The different fertilizer treatments continued through a period of years offered an opportunity to observe resulting changes in the soil solution. Six smaller, followed by 15 full fertilizer applications, made at intervals of six months, preceded taking the soil samples. Shortly prior to the fertilization of May, 1925, soil samples were taken from the upper 6 to 8 inches, and air dried and ground previous to testing. The acidity of the soil of the different plats as determined by the hydrogen-ion concentration in the soil extract is shown in Table 5.

TABLE 5.—*Soil acidity of the differently fertilized plats as shown by the hydrogen-ion concentration in the soil extract*[1]

Division	Rate of fertilizer application per tree	Plats receiving—							
		K	P	N	NK	PK	NP	NPK	O
	Pounds	*pH+*	*pH+*	*pH+*	*pH+*	*pH+*	*pH+*	*pH+*	*pH+*
1	¼	7.0	6.9	7.1	6.8	7.2	7.1	6.8	7.2
2	½	6.6	6.7	6.7	6.5	6.8	6.6	6.3	7.3
3	1	7.3	6.6	6.8	6.1	6.8	6.6	6.2	7.3
4	2	7.1	6.7	6.8	5.8	6.9	6.7	6.1	7.2
5	4	7.2	6.7	6.8	5.7	7.0	6.1	6.2	7.4

[1] Clark and Lub's colorimetric method was used to determine acidity.

The soil reaction was the same for the five untreated plats. The plats to which potassium sulphate alone was applied, even in the maximum quantities, showed no change in reaction. Ammonium sulphate alone, and acid phosphate alone and in combination with potassium sulphate, only very slightly increased soil acidity. The increase was the same for the three treatments, and was as great for the one-half pound application as for the 1, 2, or 4 pound applications. A greater increase in acidity was produced by ammonium sulphate and acid phosphate in combination and by the complete fertilizer. In the former instance the one-half pound was as effective as the 1 and 2 pound applications, but there was a sharp increase in acidity with the 4-pound application. Where the complete fertilizer was given, the 1, 2, and 4 pound rates caused little increase in acidity over the one-half-pound rate.

The maximum change in soil reaction was produced by ammonium sulphate and potassium sulphate in combination. Here there was a continuous increase in acidity in harmony with the rate of application. The plat showing the highest acidity also held the record for maximum production. As yet this acidity has shown no unfavorable effects on either growth or yield. The length of time required for acidity to increase to the point of injury under continued heavy applications has not as yet been determined.

The different fertilizers affected differently the physical condition of the soil, as is shown by the rate at which the soil particles settled when they were shaken with water. Acid phosphate was the most effective agent in flocculation. The soil particles of samples from plats which were treated with acid phosphate, either alone or in combination, when well shaken with water settled

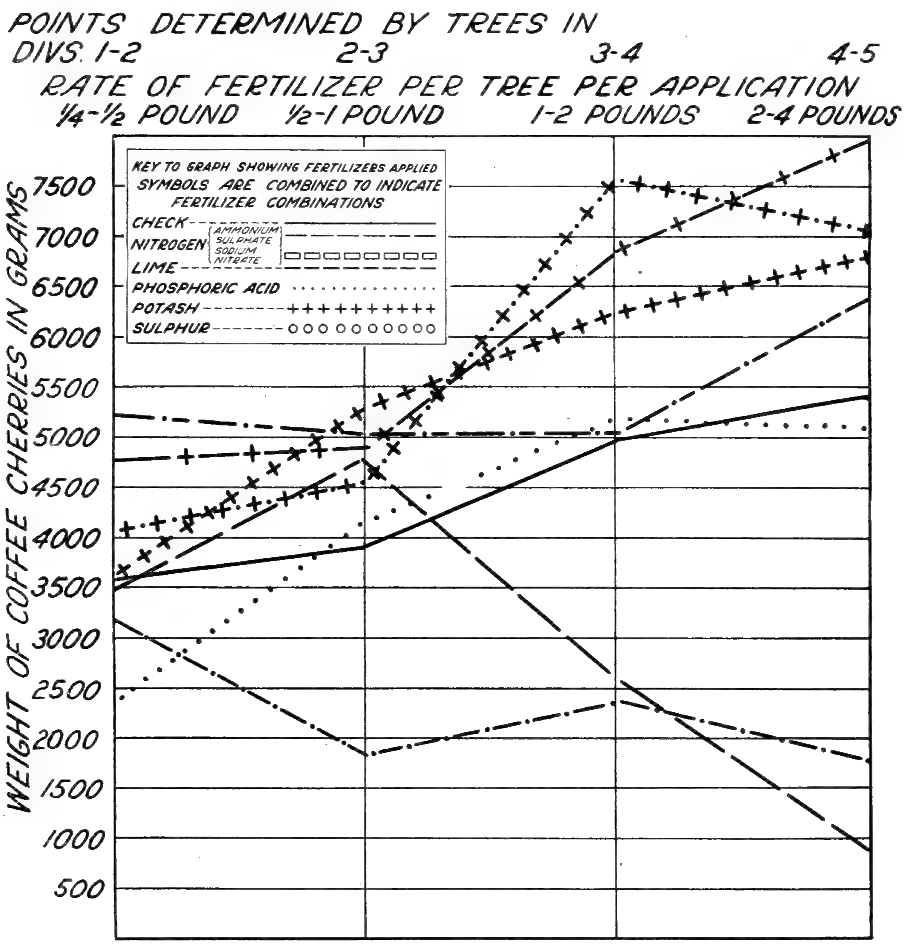

FIG. 4.—Average production per tree for the year 1924. South Field plats

in 6 to 10 hours, leaving a clear solution above, whereas samples from the untreated plats were still muddy at 36 to 40 hours after shaking. Second to acid phosphate plats came those receiving ammonium sulphate and potassium sulphate in combination at the two heaviest application rates, this effect not following the lighter applications, however. There was only a slight improvement in flocculation in the plats treated with ammonium sulphate alone and no improvement in those treated with potassium sulphate alone.

PADANG AND ERECTA PLATS

In contrast with the uniformity of slope found in the West Field plats, the Padang and Erecta plantings are on rather steep slopes,

such as are typical of land usually set with coffee. As has been pointed out, this type of land is not well suited for making comparative plantings. In 1912 the Erecta planting contained 199 trees in 25 rows running with the slope. These rows were grouped into 5 plats, each containing trees on both the upper and the lower slope. During the period covered, a number of the trees died and had to be replaced by others which were not included for yield averages until they were 5 years old. In 1924, 187 trees remained in the planting.

The two Padang plats contained 115 trees in 1912 and 105 trees in 1924. Though approximately uniform as to area, the advantage

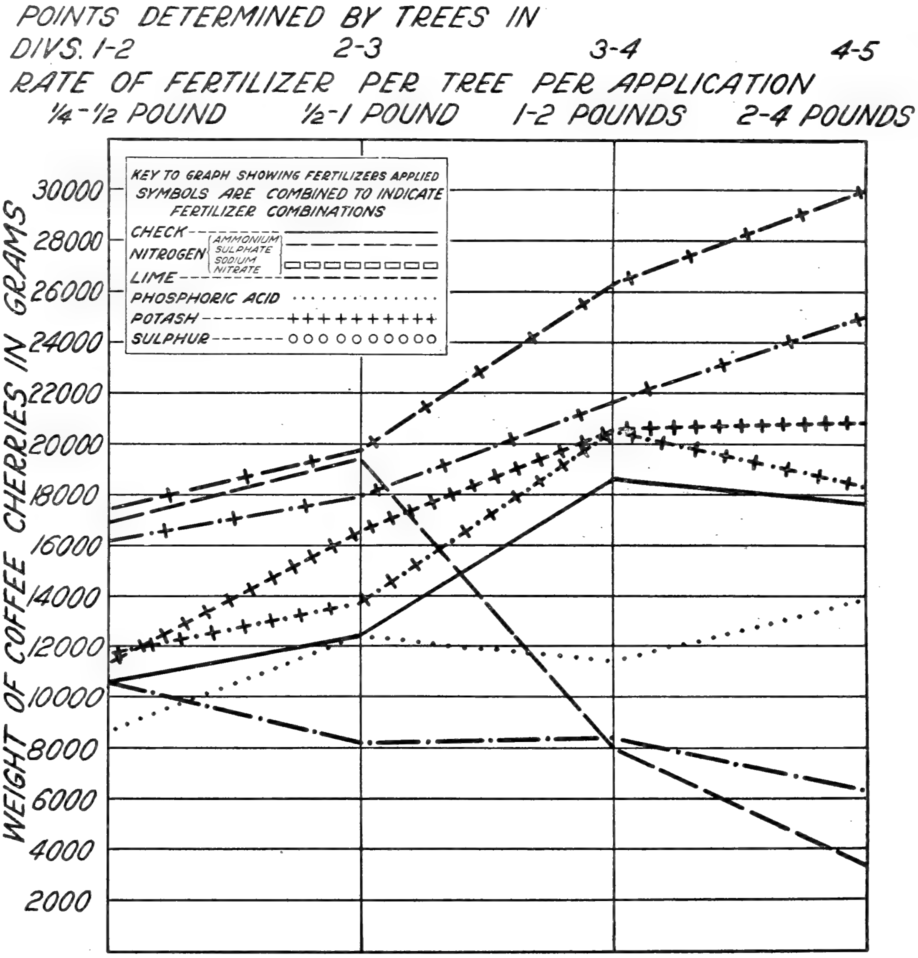

FIG. 5.—Average production per tree for the 8-year period 1917–1924. South Field plats

of location lay with the check, which contained fewer trees on the less fertile upper slope.

All plats were set with young seedlings in 1909. Beginning with 1910 and continuing to date, the trees have been fertilized semi-annually, usually in December and in May or June. The plats were treated with a 7 : 10½ : 14 fertilizer combination, the initial application being made at the rate of one-half pound per tree, and subsequent applications at the rate of 1 pound each. Individual terraces were

provided for the trees to form platforms into which the fertilizer could be worked.

The 5 Erecta plats included a check, 1 plat which received complete fertilizer, and 3 each of which lacked one element in the fer-

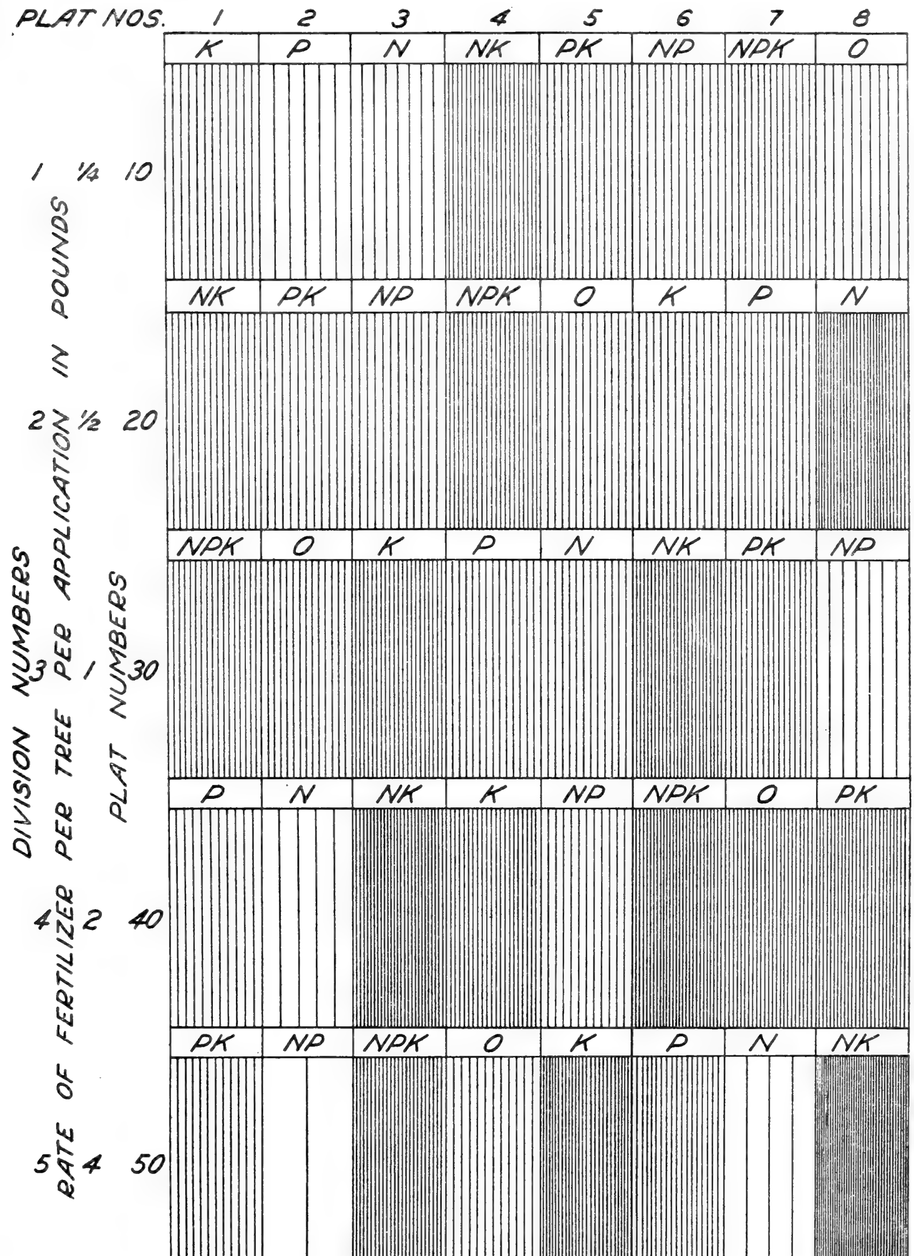

FIG. 6.—Total average yield per tree for the 8-year period 1917–1924, each line representing the production of 1 kilogram of coffee cherries. Plats arranged in relative position in South Field

tilizer combination. The Padang plats included a check, and 1 which received the same kind of fertilizer as that applied to the Erecta plat receiving complete fertilizer plus a liberal quantity of stable manure. Fifteen pounds of manure per tree were given in

the first two applications, and a 5-gallon measureful was applied thereafter as a surface mulch subsequent to fertilization.

Measurements of height, taken annually from 1912 to 1916, inclusive, the period of rapid stem elongation, showed that, of the

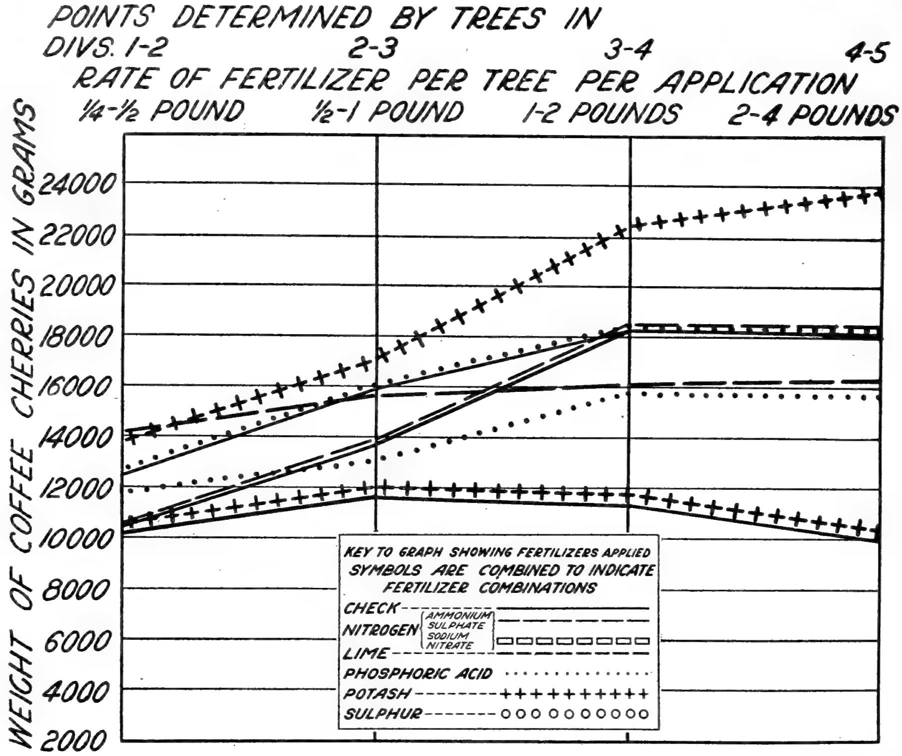

FIG. 7.—Total average production for the 8-year period, 1917–1924, of those trees which received any one element in contrast with those to which that particular element was not applied, the latter or check being represented by a similar symbol underscored

Erecta plats, each of the 3 plats receiving nitrogen averaged higher than either of the other 2, with the NP plat leading. Table 6 shows the average annual production per tree in liters of cherries.

TABLE 6.—*Average annual production of coffee cherries per tree, Padang and Erecta plats with different fertilizer treatments*

Year	Yields with the different treatments						
	Padang		Erecta				
	Check	NPK and manure	NK	NP	Check	PK	NPK
	Liters	*Liters*	*Liters*	*Liters*	*Liters*	*Liters*	*Liters*
1912	1.4	2.0	0.4	0.9	0.1	0.2	0.5
1913	2.8	3.8	.8	1.5	.3	.2	1.2
1914	2.5	3.4	1.0	1.2	.2	.2	.8
1915	3.5	3.6	1.4	2.0	.5	.6	2.0
1916	2.1	3.6	1.0	1.1	.3	.6	1.6
1917	5.1	3.6	5.7	5.7	2.8	2.8	8.4
1918	1.2	1.9	1.2	.8	.3	.5	1.6
1919	4.7	4.0	3.2	2.9	1.9	2.5	5.8
1920	.8	1.0	.7	1.2	.7	.8	1.9
1921	.5	1.1	1.9	2.3	1.2	2.0	5.0
1922	5.0	6.1	2.6	3.0	2.9	3.4	5.2
1923	1.8	3.7	2.0	1.6	1.6	3.2	6.1
1924	2.9	4.1	1.6	1.2	1.9	2.5	3.5
Total	34.3	41.9	23.5	25.4	14.7	19.5	43.6

In both plantings complete fertilizer resulted in increased production, moderately so with Padang, and to a pronounced degree with Erecta. Were only the first four crops of the Erecta planting to be considered, it might easily be inferred that nitrogen was the limiting element since the three plats receiving it produced approximately three to five times as great a yield as the check or the PK plat, with the NP plat leading. If the last six crops are considered as a unit, it is seen that the NPK plat produced more than any other two plats combined, and the plat from which nitrogen was omitted ranked ahead of the other two plats receiving incomplete fertilizer. The NPK plat for the 13-year period as a whole produced approximately three times as much as the check plat, and sufficiently in excess of the plats receiving incomplete fertilizer to indicate the need of supplying all three elements to the soil. Figures 8 and 9 graphically show the yields, the effect of fertilizer on yield, and the wide variation in production from year to year.

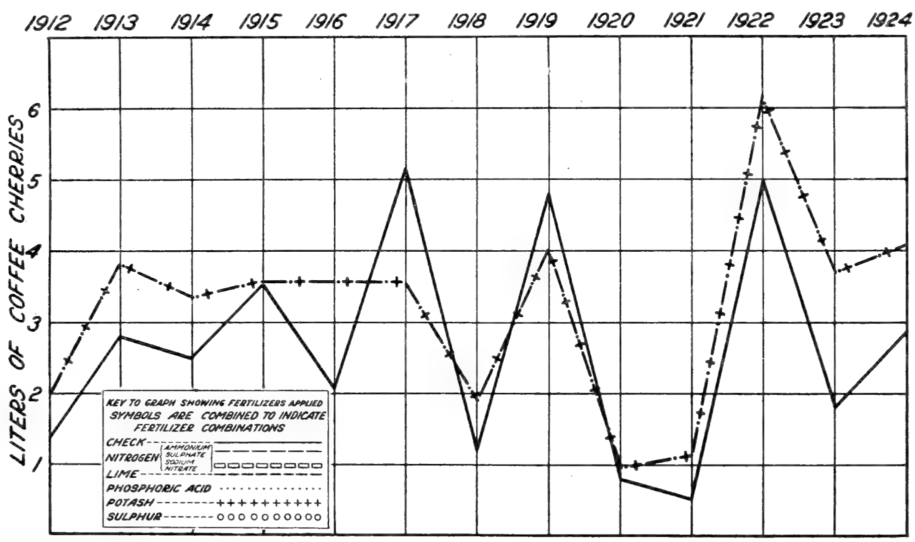

FIG. 8.—Average annual production per tree of Padang plats with and without fertilizer

To determine the effect of fertilizer on size of fruit, counts per liter were made of samples of Padang cherries at intervals during six years, and of samples of Erecta cherries at intervals during four years, involving some 31,486 fruits. The average number of Padang cherries per liter from check plats differed from that of fertilized plats by less than 1 per cent, whereas those from the Erecta plats differed by 13 per cent. The size of cherry, as indicated by the number in a liter, bore an interesting relation to the yield per tree for the period involved. The total yield of the Padang plats showed a difference of 5 per cent for the period, and the size of cherry less than 1 per cent. The Erecta NPK plat produced 235 per cent more than its check, and a liter of the former contained 13 per cent more cherries than were required of the latter to fill the measure. Similarly for the five plats, the size of cherry was in direct relation to the yield, the sequence of the plat yields being the same as that of the average number of cherries per liter. In other words, the only

observed effect of fertilizer on size of cherry was indirect. A notable increase in yield was accompanied by a slight reduction in size of cherry.

COMPARISON OF AMMONIUM SULPHATE AND SODIUM NITRATE

Several comparative tests were made to learn the value of ammonium sulphate and sodium nitrate as fertilizer for coffee.

BOURBON PLATS

Sixty trees of Bourbon coffee were selected for one of the tests. The seed was planted in April, 1915, and the resulting seedlings were set in heavy clay soil in the fall of 1916. Later some replacements

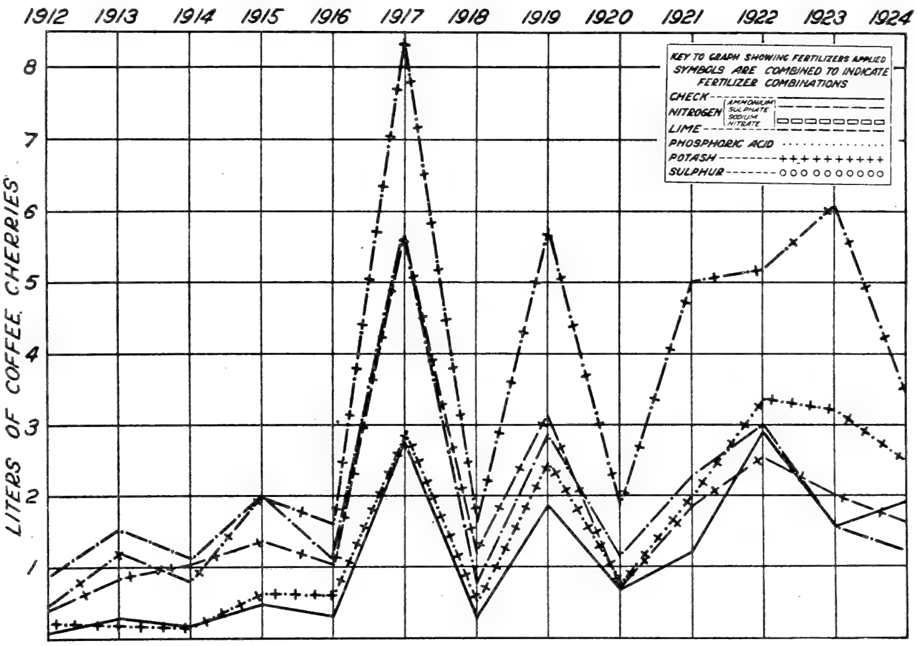

FIG. 9.—Average annual production per tree of Erecta plats to which different combinations were applied

of weak and missing trees were made from the original nursery. The planting contained 12 rows of 5 trees each, spaced 8 by 8 feet. The slope was steeply but very uniformly inclined and the short rows ran with the slope. Although the lower trees in each row were in more fertile soil than the upper trees, 1 row as a unit was very uniform with another as to elevation and soil. The 2 treatments were given to alternating rows throughout the planting. The plats, each containing 30 trees set in 6 alternating rows, furnished strictly comparable conditions for making the test.

Fertilizers were applied semiannually. The first four applications, December, 1917, to June, 1919, inclusive, were of nitrogen only; after that time phosphoric acid and potash were provided, the rate and formula being, as was the case with the Padang and Erecta tests, 1 pound per tree per application of a 7 : 10½ : 14 combination.

As has been the case with many other coffee plantings at the station,[4] the trees on the upper slope grew slowly, whereas those on the lower grew vigorously. That growth was greatly influenced by another factor as well was shown by measurements of height taken in January, 1920 (fig. 10), and of trunk diameter made in August, 1921. All rows treated with ammonium sulphate except one surpassed in height the highest row treated with sodium nitrate. The total height of the former was 28 per cent greater than that of the rows treated with sodium nitrate. Figure 11 graphically shows the trunk diameters and also the pronounced effect of the form in which nitrogen was applied. Use of ammonium sulphate resulted in an increase in yield of 63 per cent for the 7-year period, and fully demonstrated its superiority over sodium nitrate under the conditions of the test. It is not known what benefit may have been derived from sodium nitrate since there was no unfertilized check plat. Table 7 shows the annual yields of the two plats.

TABLE 7.—*Comparative yields of Bourbon coffee cherries on plats receiving ammonium sulphate and sodium nitrate*

Year applied	Plat 1, ammonium sulphate	Plat 2, sodium nitrate	Yield of plat 1 in percentage of plat 2
	Liters	*Liters*	*Per cent*
1918	5.5	4.2	131
1919	43.5	30.1	145
1920	60.6	14.9	407
1921	152.3	88.4	172
1922	89.3	57.8	154
1923	217.3	136.6	159
1924	127.7	94.1	136
Total	696.2	426.1	163

BISCHOFF AND LOPEZ PLANTATION PLATS

Field tests on the Bischoff and Lopez plantations were undertaken to ascertain the effectiveness of sodium nitrate as a fertilizer for coffee.[5] Later, comparative tests of ammonium sulphate were added.

On the Bischoff plantation two $\frac{1}{10}$-acre plats were fertilized with sodium nitrate at the rates of 150 (plat 1) and 300 (plat 3) pounds, respectively, per acre per application. Between the two lay a $\frac{3}{40}$-acre plat (plat 2), which was used as a check as uniform trees were not available for three $\frac{1}{10}$-acre plats. The soil was red clay covered with an abundant natural mulch derived from a uniform and suitable shade. The coffee trees were said to have been set 4 years previously, and were apparently lacking in vigor. Sodium nitrate was applied in February, July, and December, 1916, and again in June and December, 1917. Crop yields were recorded in pounds. In the fall of 1916, plat 1 yielded an average of 2 pounds per tree, plat 2 yielded 2.1 pounds, and plat 3, 2.2 pounds. In 1917, plat 1 yielded an average of 1 pound per tree, plat 2, 1.3 pounds, and plat 3, 1.2

[4] Porto Rico Sta. Bul. 21, Some Profitable and Unprofitable Coffee Lands.
[5] Originally carried on in cooperation with Chilean Nitrate Propaganda Agency.

pounds. Changes incident to the war prevented the continuation of the test. During the brief period in which it was under way no apparent benefit in vigor or yield was observed to result from sodium nitrate.

The second group of plats, located on the Lopez plantation (Las Vegas) consisted originally of four $\frac{1}{10}$-acre plats, to which a fifth was later added. The 4 original plats contained 3 rows each and had guard rows between plats. The trees ranged in number from 98 to 115 per plat in 1916, and from 95 to 112 in 1924. The fifth plat contained 121 trees. The plats are located on a uniform and gentle slope and the soil is a stiff, reddish-brown clay. The first 4 plats have approximately the same elevation and plat 5 is slightly lower on the slope. The coffee trees said to be 6 years old were in moderately good condition and set in rows approximately 9 feet apart. The 1916 crop was measured in accordance with the usual plantation practice. After that the crop was weighed also as a check on the recorded measure. The two periods into which the experiment was divided by a change in treatment in 1920 require separate consideration. The 1920 crop may be included in the first period. Since the plats varied in the number of trees they contained, production should be considered both per unit area (fig. 12) and per individual tree (fig. 13).

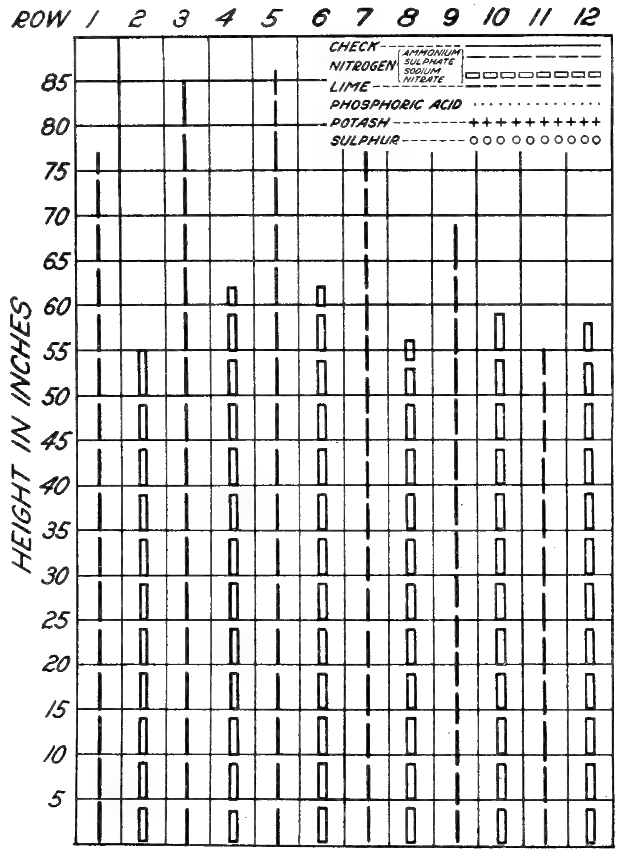

FIG. 10.—Average height per tree of Bourbon coffee, January, 1920

Eight applications were given between February, 1916, and June, 1919, plat 1 receiving sodium nitrate (5 pounds per application), plat 2 nothing (check), plat 3 sodium nitrate (15 pounds), and plat 4 sodium nitrate (30 pounds). Four applications of sodium nitrate and acid phosphate (15 pounds each per application) were given plat 5 between December, 1917, and June, 1919. No increase in yield attributable to sodium nitrate was apparent at the end of the first period. The check plat remained in the lead except for the peak year 1919. From 1916 to 1918, inclusive, the average production per tree for plats 1 to 4, inclusive, showed no great difference, plat 2 rank-

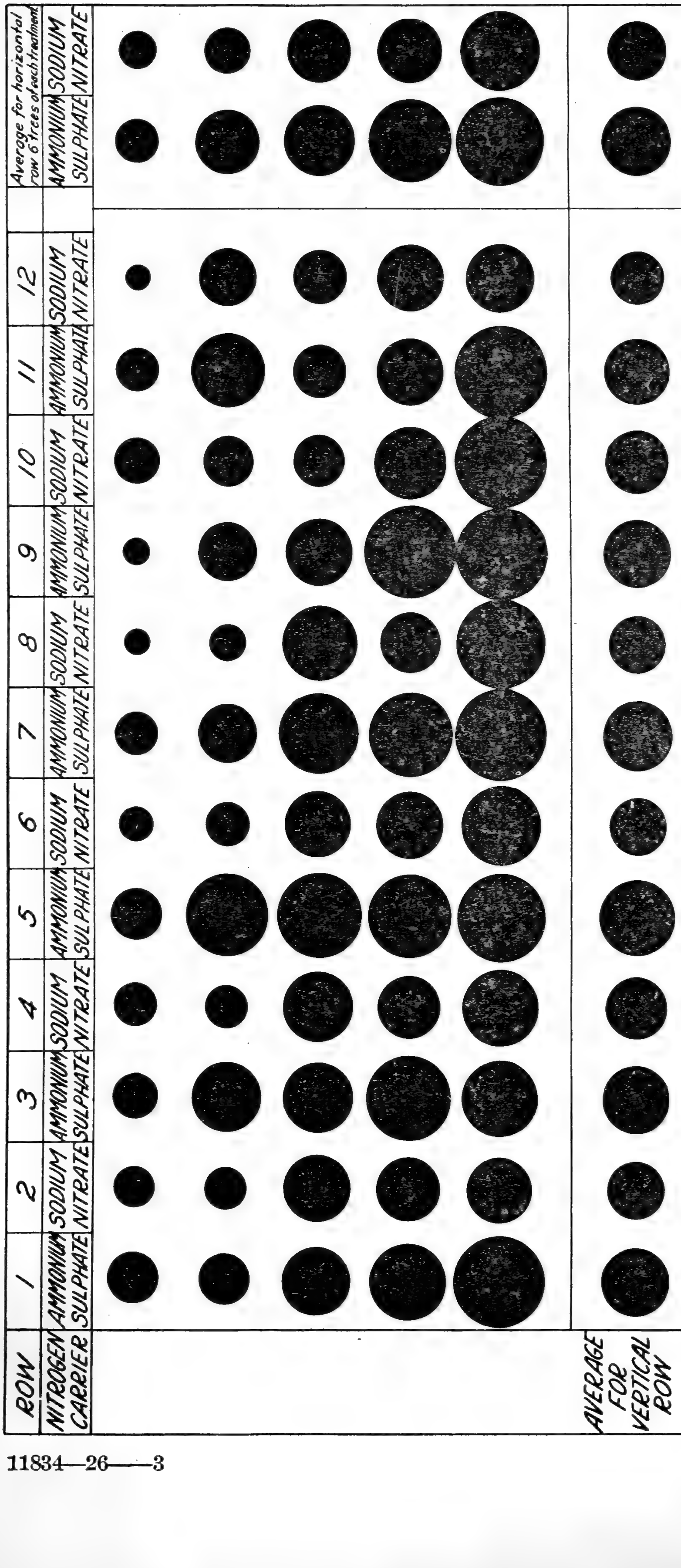

FIG. 11.—Trunk diameter of Bourbon coffee at 3 inches above base, measured August, 1921, relative positions of trees as in field

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ing high and plat 4 low. Plat 5, which received acid phosphate in addition to sodium nitrate, ranked high in 1919, but very low in 1918 and 1920. The treatment was changed in January, 1920, because of the poor performance of the fertilized plats.

Semiannual applications have been made from January, 1920, to date, plat 1 receiving ammonium sulphate (11¼ pounds per application), plat 2 nothing (check), plat 3 ammonium sulphate (11¼ pounds), acid phosphate (15 pounds), and potassium sulphate (5

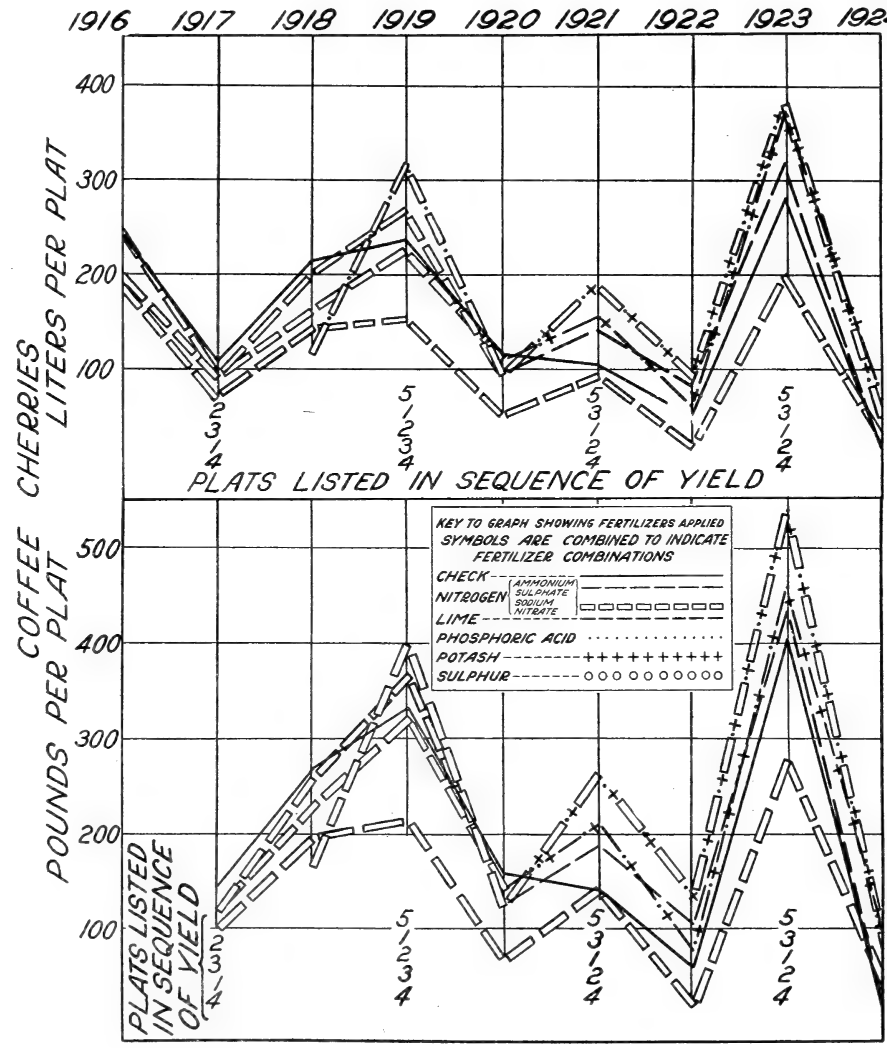


FIG. 12.—Yield from coffee plats of $\frac{1}{10}$ acre each at Lopez plantation

pounds), plat 4 sodium nitrate (15 pounds), and plat 5 sodium nitrate and acid phosphate (15 pounds each), and potassium sulphate (5 pounds), the formula combining nitrogen, phosphoric acid, and potash in approximately equal quantities. The production of plat 4, which received sodium nitrate alone, on the whole fell below that of the check. Plat 1, which received ammonium sulphate alone, surpassed the check in yield during three years and approximated it in the very small crop of 1924. Plats 3 and 5, receiving complete

fertilizer, surpassed the check each year in production per tree and per plat for the 1921–1924 period. The difference in production in the peak year of 1923 was pronounced. Evidently the complete fertilizer produced a decided increase in yield. The effectiveness of ammonium sulphate alone was less pronounced and no benefit whatever was observed as a result of using sodium nitrate alone.

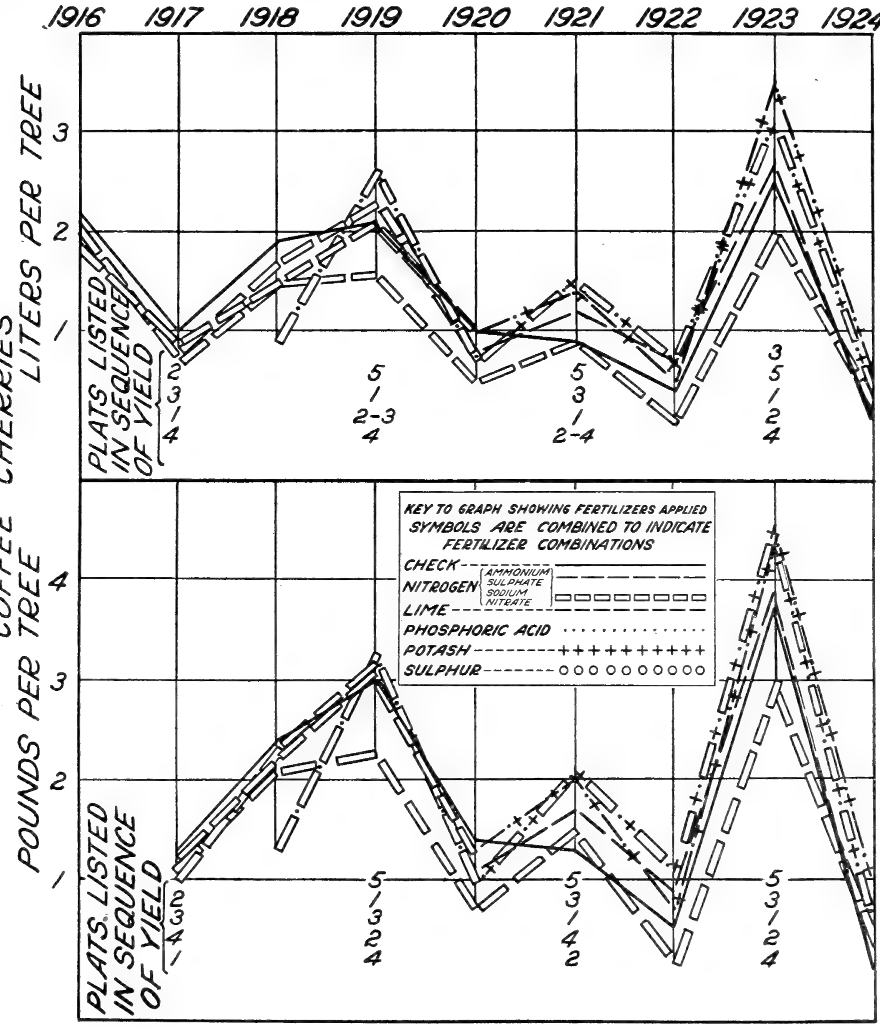


FIG. 13.—Average yield per tree of plats at Lopez plantation

WEST FIELD PLATS

In 1911 for fertilizer tests a planting of 33 plats of 18 trees each was made on an almost level plain promising uniform conditions. The tests were discontinued in 1915, however, because of the unsatisfactory growth made by the trees owing to poor drainage. The salient features of the test are given herewith:

The basal formula used was 7:10½:14 and the rate one-half pound per application. Five applications were made from 1912 to 1914. In addition to complete fertilizer, combinations of two elements, single elements, lime, guano, coffee pulp, and manure were

included in the fertilizer scheme. In the complete fertilizer the nitrogen was carried in ammonium sulphate. In the incomplete, ammonium sulphate was applied to three plats and sodium nitrate to three. Nine plats were given no fertilizer, and some of them varied in cultural treatment.

The nine plats making the best growth by October, 1913, included six of the seven receiving ammonium sulphate and only one of the three treated with sodium nitrate. The ammonium sulphate plat not included received lime in addition to complete fertilizer. The nine plats making the poorest growth included two receiving lime, one basic slag, and one acid phosphate and potash in combination, but no others with mineral fertilizers. The plat receiving lime at the heavier rate, 2 pounds per tree each application, was adjacent to that treated with complete fertilizer alone at double the basal rate, or 1 pound per tree. At this time the former averaged 12.9 inches high per tree, and the latter 20.7 inches. The measurements of October, 1913, indicated that nitrogen in the form of ammonium sulphate was beneficial, whereas no apparent benefit was had from liming. The five plats of tallest trees, as measured in October, 1914, had received ammonium sulphate. The plats receiving complete fertilizer ranked first, fourth, eighth, and ninth, respectively. None of the ten poorest plats received any mineral fertilizer other than lime or basic slag. The poorest plat was that receiving the heavier applications of lime. Trees on this plat averaged only 21 inches high, whereas those on the adjacent plat, which received complete fertilizer, averaged 45.5 inches high.

Adjacent to the plat receiving ammonium sulphate alone and to the two plats receiving ammonium sulphate in combination with potash and with acid phosphate, respectively, were three other plats which received equivalent quantities of nitrogen in the form of sodium nitrate. The average height per tree of plats treated with ammonium sulphate was 48.4, 44.6, and 52.9 inches, respectively, per plat, whereas that of the correspondingly treated sodium nitrate plats was 29.4, 32.3, and 34.6 inches, respectively, per plat. Some of the trees produced a few cherries in 1913, but not enough to indicate fertilizer effects. The production showed an increase in 1914, but was still very small. Of 20 fruiting plats, the 5 leading ones received ammonium sulphate. The yields of the 10 best plats ranged in 1915 from 2,133 to 9,351 cherries, and the yields of the 10 poorest plats ranged from nothing to 164 cherries.

The plats of highest yield, named in the order of their merit, received complete fertilizer, ammonium sulphate and potash, complete fertilizer in double quantity, complete fertilizer and lime, guano in double quantity, complete fertilizer and manure, nothing, manure in double quantity, ammonium sulphate and acid phosphate, and ammonium sulphate alone. These 10 plats included all of the 7 receiving ammonium sulphate, but none of the 3 receiving sodium nitrate.

The 10 plats of poorest yield, 2 giving nothing, included those receiving lime alone, sodium nitrate alone, and sodium nitrate in combination with acid phosphate, but no other fertilized plat.

The yields of the three plats receiving ammonium sulphate for comparison with sodium nitrate were 7,655, 2,133, and 2,140 cherries,

respectively, or a total of 11,928, and the yields from the three plats receiving sodium nitrate were 1,019, 102, and 164 cherries, respectively, or a total of 1,285 cherries, which was less than one-ninth the production made by the ammonium sulphate treated plats.

The production, as well as the measurements of growth, indicated a favorable effect of the ammonium sulphate as compared with applications of sodium nitrate or lime.

EXPERIMENTS IN LIMING

A planting of more than 100 trees which were set in 1909 was divided into two plats to provide a site for liming experiments. After the 1913 crop was harvested one plat was uniformly limed (probably four-fifths air-slaked and one-fifth quicklime) at the rate of little more than 3 pounds per square meter of surface. Previous to liming the soil was cultivated. Table 8 gives the yields during five years.

TABLE 8.—*Yields of cherries before and after liming*

Year	Average yield per tree of check plat	Average yield per tree of limed plat	Yield of limed plat expressed in percentage of check
	Liters	*Liters*	
1913 (before liming)	1. 08	1. 18	109
1914 (after liming)	1. 23	1. 33	108
1915	1. 85	1. 55	84
1916	1. 33	1. 69	127
1917	2. 38	2. 29	96
Total for 1914–1917 period	6. 79	6. 86	101

The year preceding the application of lime the average yield per tree of the plat subsequently limed surpassed that of the check by 9 per cent. With the yield of the check considered as 100 per cent, the yield of the limed plat for the years subsequent to lining was 108 per cent for the first year, 94 per cent for the first two years (combined yield), 104 per cent for the first three years, and 101 per cent for the first four years. The results failed to show any appreciable benefit from liming.

Two other tests were made on a smaller scale, the trees being limed annually at the rate of 1 to 2 pounds per tree. The results were not in accord, one lot yielding more and the other less than its check.

POT TESTS

COMPLETE AND INCOMPLETE FERTILIZERS

To learn the effect of fertilizers on yield under more controlled conditions than were possible in the field, several tests were made with coffee seedlings set in 5-gallon containers. In March, 1924, heavy red clay soil, removed to a spade's depth from a hilltop on which coffee had made poor growth, was placed in the containers, using coarse gravel in the bottom for drainage. A vigorous seedling hav-

ing three pairs of true leaves was set in each container on April 28. Measurements, made a month later, showed that the plants had attained a height of between 5 and 6 inches. All were green and apparently in vigorous condition. Subsequent measurements were made every three months.

Fertilizer, at the rate of one-twentieth pound per pot per application, was given May 28 and November 28, 1914, and June 3, 1915. The basal formula used was nitrogen (7 per cent), phosphoric acid (10½ per cent), and potash (14 per cent). In addition to the complete fertilizer, the seedlings received nitrogen, phosphorus, and potash in combinations of two and singly. Where an incomplete fertilizer was applied each element was the equivalent of the same element applied in the complete fertilizer.

The fertilizer carriers were ammonium sulphate, acid phosphate, and potassium chloride in the first application, and ammonium sulphate, acid phosphate, and potassium sulphate in the two subsequent applications. Each treatment was given in triplicate. In addition to the regular check lot, three containers were filled with soil dug about 50 yards distant from the first, and near better coffee. This lot is marked " O′ " in the diagram and tables.

At the time of the first fertilizer application the difference in combined height between any 2 groups of 3 trees was ½ to 1 inch only. Nine months later each group receiving nitrogen surpassed the check in height and all others fell below it. The 4 nitrogen groups averaged 97 inches high and the other five 83.7 inches. From November 28, 1914, to February 27, 1915, each group receiving nitrogen increased in height between 31 and 34 inches, whereas the others for the same period showed an increase of only 18 to 23 inches. From May 28 to August 28, 1915, the 4 nitrogen groups increased in height 13, 14, 18½, and 19 inches, respectively, whereas of the 5 groups receiving no nitrogen 3 increased 1, 3, and 7½ inches, respectively, and 2 failed to increase. The difference in height between the check and the other groups is shown in Table 9.

TABLE 9.—*Difference in height between check and fertilized groups of three young coffee trees each grown in cans*

Fertilizer applied	Date of measurement						
	1914			1915			
	May 28	Aug. 28	Nov. 28	Feb. 27	May 28	Aug. 28	Nov. 27
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
N	+1	−6	−10½	+1½	+13½	+25½	+18
P	+½	−4	0	−3	−1½	+½	−5
K	+1	−3½	−8½	−6½	+2	+1	−6
NP	0	+2	+9½	+20	+27½	+40½	+32
NK	+1	0	−4½	+5½	+12	+30½	+24½
PK	0	+2	−4	−2½	−½	+6	0
NPK	+½	+4½	−4	+9	+20	+37½	+31½
O	0	0	0	0	0	0	0
O′	+½	−8	−9	−9½	−7½	−8½	−15½

The effect of nitrogen for increasing growth is clearly evident. Both phosphoric acid and potash, with the former leading, evidently still further increased growth when used in combination with ni-

trogen. The growth of the different groups is shown graphically in Figure 14.

In April, 1915, five noninterested persons who were asked to name, in their opinion, the groups showing the darkest leaf coloring un-

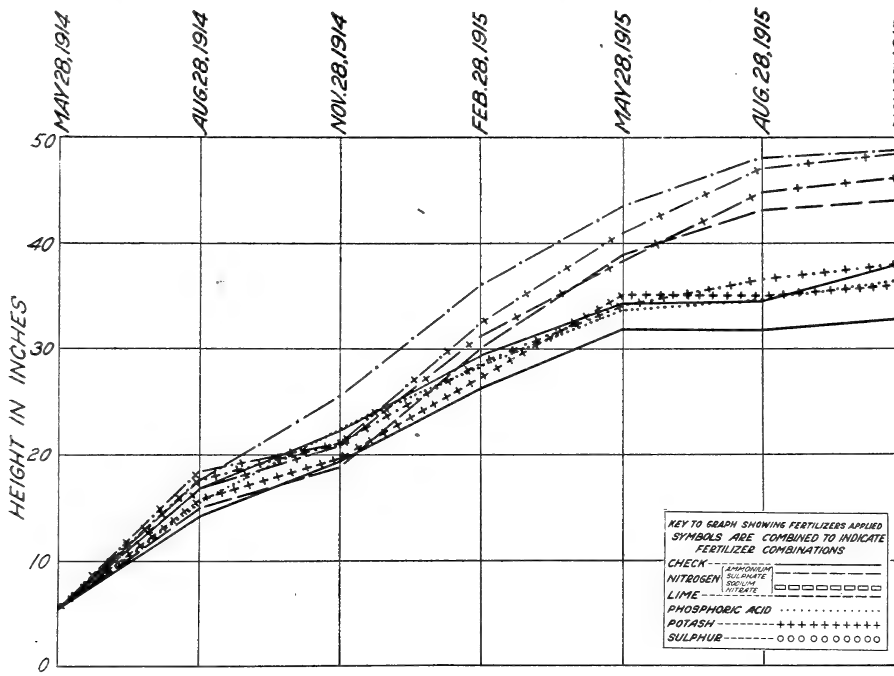


FIG. 14.—Average height of young coffee trees grown in cans. Nitrogen has increased growth

hesitatingly pronounced the four nitrogen-treated groups of darkest green color. Counts of the leaves per tree were made June 19, 1915. Table 10 shows the number of leaves per tree.

TABLE 10.—*Number of leaves on young coffee trees grown in cans with different fertilizer treatments*

Fertilizer applied	Number of leaves				Variation from check	Percentage of check
	Tree No. 1	Tree No. 2	Tree No. 3	Total		
N	157	135	150	442	+135	144
P	85	117	110	312	+5	102
K	98	104	105	307	0	100
NP	176	152	157	485	+178	158
NK	76	160	165	401	+94	131
PK	82	114	108	304	−3	99
NPK	165	170	150	485	+178	158
O	102	112	93	307	[1]	100
O'	85	80	90	255	−52	83

[1] Check.

All groups receiving nitrogen showed a heavy increase in foliage. The lengths of 50 similarly placed leaves on each tree were measured to one-eighth inch. Variation between the check and any other group was less than 7 per cent, and no correlation could be seen between the kind of fertilizer applied and leaf length. At

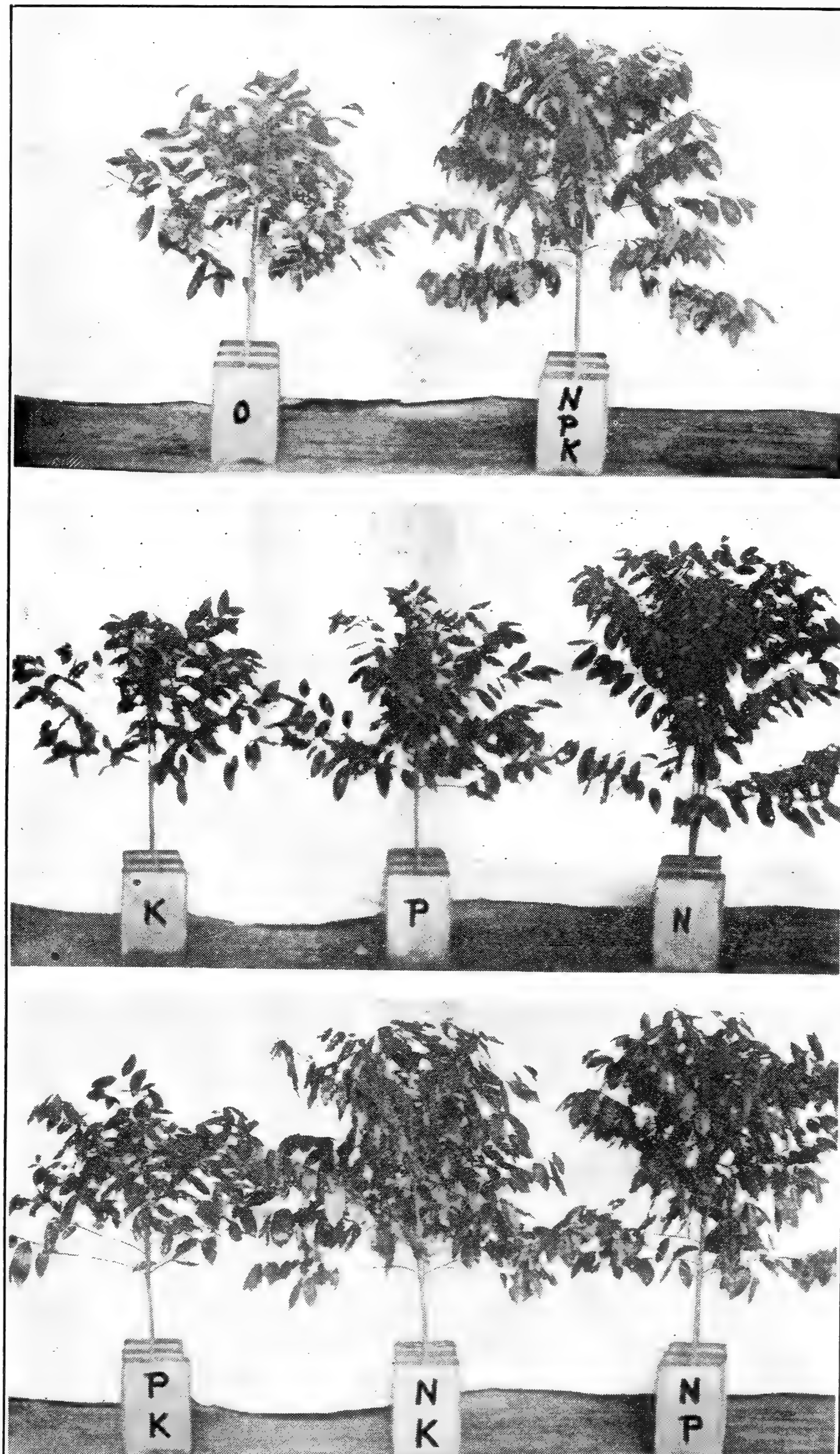
the close of the experiment, 18 months after the first fertilizer application had been made, the trees were photographed, those of each group being placed in file, thus appearing as a unit (Pl. 2). The leaves were picked November 29, 1915, and weighed. Table 11 shows the effect of fertilizers on development of the young trees as determined by weights at the close of the test.

TABLE 11.—*Effect of fertilizer on development of young coffee trees in cans as shown by weights at close of test*

Fertilizer applied	Tree No. 1	Tree No. 2	Tree No. 3	Total	Variation from check	Weight reduced to percentage of check
WEIGHT OF LEAVES						
	Grams	*Grams*	*Grams*	*Grams*		
N	219	219	212	650	+367	230
P	92	100	53	245	−38	87
K	96	79	55	230	−53	81
NP	228	203	167	598	+315	211
NK	105	215	204	524	+241	185
PK	89	84	75	248	−35	88
NPK	222	256	155	633	+350	224
O	117	90	76	283	(1)	100
O′	62	87	67	216	−67	76
WEIGHT OF TRUNK AND BRANCHES						
N	251	244	308	803	+331	170
P	116	171	169	456	−16	97
K	149	141	141	431	−41	91
NP	255	286	250	791	+319	168
NK	117	280	314	711	+239	151
PK	165	157	150	472	0	100
NPK	257	308	237	802	+330	170
O	154	172	146	472	(1)	100
O′	124	140	149	413	−59	88
WEIGHT OF ROOTS						
N	110	102	105	317	+120	161
P	44	82	67	193	−4	98
K	62	57	69	188	−9	95
NP	79	112	98	289	+92	147
NK	48	92	103	243	+46	123
PK	64	74	74	212	+15	108
NPK	78	105	85	268	+71	136
O	63	70	64	197	(1)	100
O′	53	59	69	181	−16	92
TOTAL WEIGHT						
N	580	565	625	1,770	+818	186
P	252	353	289	894	−58	94
K	307	277	265	849	−103	89
NP	562	601	515	1,678	+726	176
NK	270	587	621	1,478	+526	155
PK	318	315	299	932	−20	98
NPK	557	669	477	1,703	+751	179
O	334	332	286	952	(1)	100
O′	239	286	285	810	−142	85

[1] Check.

The weights stand in a very interesting relation to the fertilizer applied. With one exception the weight of leaves from each nitrogen-fertilized tree exceeded that of leaves from each tree receiving no nitrogen. The weight of leaves from the nitrogen-treated trees



COFFEE SEEDLINGS AT 18 MONTHS FROM FIRST FERTILIZATION. NITROGEN HAS GREATLY STIMULATED DEVELOPMENT

averaged 200 grams per tree, and 9 of the 12 trees exceeded this weight. The weight of leaves from nonnitrogen treated trees averaged 81 grams, and only 1 of 15 exceeded 100 grams.

On November 30, 1915, the trees were cut at the surface of the ground and the trunk and branches were weighed. The weight of the trees receiving nitrogen averaged 259 grams, whereas that of trees receiving no nitrogen averaged 150 grams.

The roots were carefully washed and air-dried for several days prior to weighing. Because of the heavy soil, it was impossible not to lose some fine roots. The weight for all trees receiving nitrogen averaged 93 grams, whereas for the others it averaged 65 grams.

In this test it was very evident that nitrogen exerted a marked influence in stimulating the development of the young trees as was shown in their greatly increased number of leaves, amount of woody growth above ground, and root growth.

COMPARISON OF AMMONIUM SULPHATE, SODIUM NITRATE, LIME, AND SULPHUR

In the West Field plat tests the favorable effect of ammonium sulphate was very marked, but this was not true of sodium nitrate or of lime. The sulphur was therefore further studied in pot tests.

The bottom of 5-gallon cans was lined with coarse pebbles to permit of drainage, and the containers were filled with red clay soil which was removed to a spade's depth from a hillside and thoroughly mixed. In a test it was found that 0.992 gram of hydrated lime was required to neutralize 1 kilogram of soil. The seedlings, from the seed of a single tree, planted May 26, 1915, were each set in cans on September 13, 1915. The treatment was given in triplicate. Group 1 received ammonium sulphate (8 grams per can per application); Groups 2 to 6, inclusive, sodium nitrate (4. 8, 10, 12, and 16 grams, respectively); Groups 7 to 12, inclusive, hydrated lime (at the rates of 1,000, 2,000, 4,000, 8,000, 16,000, and 32,000 pounds, respectively, per acre); and Group 13 was left untreated (check).

The lime was applied 5 days prior to transplanting the seedlings, and was twice worked through the upper layer of soil. Over 4 inches of rain fell before the trees were set. On account of the injurious effect of liming it was necessary, within the first month, to replace 3 dead trees of Group 12, and to replace a second time two of the same group, and two badly wilted trees of Group 11. At a little less than 4 months, tree 1 of Group 10 was in so poor a condition that it also was replaced.

The nitrogen was given in three applications six months apart, beginning two weeks after the seedlings were set. Quarterly measurements of height were made, starting two months after setting, and notes were taken for two years. Figure 15 graphically gives the measurements. At the second and third measuring the two groups receiving the lightest applications of lime led. The fertilizer showed its effect on the plants in leaf color before any effect appeared in height, the dark green of the fertilized trees contrasting strongly with the yellowish hue of the limed and check trees, the contrast being less pronounced in Group 2. Early in the second year the nitrogen-fertilized trees began to grow more rapidly than the lime-treated group. At the sixth measuring each group of fertilized trees surpassed the check in height with one exception, which equaled it,

whereas the trees in the limed soil with one exception fell below it. At the close of the test the trees in the four groups receiving lime at the rate of 2 tons or more per acre measured in height considerably less than the check, and the trees receiving lime at the rate of 1 ton or less per acre measured just below the check. Each group receiving nitrogen measured above the check, the difference being most pronounced for that receiving the most nitrogen. The extreme differences in height were less than 7 per cent below and 12 per cent above the check. In March, 1917, counts of the leaves per tree were made, and in September, 1917, the leaves, woody growth, and roots were weighed. Table 12 gives the results of the test.

TABLE 12.—*Effect of nitrogen and of lime on young coffee trees grown in cans*

Fertilizer applied: Kind	Fertilizer applied: Amount	Group	Number of leaves (Mar. 12, 1917): Tree No. 1	Tree No. 2	Tree No. 3	Total	Average	Weight of trees (Sept. 11, 1917): Tree No. 1	Tree No. 2	Tree No. 3	Total	Weight in percentage of check	Average weight in percentage of check
	Grams							*Gms.*	*Gms.*	*Gms.*	*Gms.*		
Ammonium sulphate	24	1	167	152	223	542	181	470	429	442	1,341	122.1	122.1
Sodium nitrate	12	2	202	179	202	583	199	465	430	369	1,264	115.1	122.9
	24	3	177	167	192	536		385	457	394	1,236	112.6	
	30	4	174	177	200	551		391	409	398	1,198	109.1	
	36	5	191	162	198	551		510	452	439	1,401	127.6	
	48	6	197	271	293	761		560	600	490	1,650	150.3	
Hydrated lime	5.9	7	126	117	130	373	134	362	373	389	1,124	102.4	99.8
	11.7	8	118	153	131	402		325	435	364	1,124	102.4	
	23.4	9	143	160	109	412		319	373	[1] 307	999	91.0	
	46.9	10	121	132	126	379		304	410	349	1,063	96.8	
	93.7	11	157	146	138	441		424	375	364	1,163	105.9	
	187.4	12	149	142	109	400		391	415	294	1,100	100.2	
Nothing (check)	---------	13	155	133	144	432	144	408	351	339	1,098	100.0	100.0

[1] The weight of tree 3 of Group 9 fails to show full development. Four branches were broken off prior to weighing, and the weight of leaves and woody growth (roots excluded) was 17 per cent less than that of the other two trees of the same group.

The marked effect of nitrogen on foliage and development of the young trees is very evident as compared with results from liming. All except two trees fruited in 1917. Group 6 gave the highest yield, followed by Group 1. The lime-treated and check trees yielded the same average number of cherries, whereas the average yield from nitrogen-treated trees was 87 per cent greater.

To permit of further comparing the effect of ammonium sulphate and sodium nitrate on coffee, another test was made, using a heavy red clay soil which was removed to a spade's depth, ground, screened, and thoroughly mixed. In March, 1922, 70 containers were each planted with 2 seedlings from a single tree of Columnaris coffee, the seed having been planted in flats the previous December. The test was divided into 7 groups of 10 containers each, of which 1 was left to serve as a check, 4 received sodium nitrate (8, 10, 12, and 16 grams, respectively), and 2 received ammonium sulphate (8 and 12 grams, respectively, per container per application). Fertilizers were applied May 3 and November 3, 1922, and May 3, 1923.

At two and one-half months following the first fertilizer application a pronounced difference was noted in growth and vigor of

trees, the ammonium sulphate groups appearing to be adversely affected by the fertilizer in proportion to the quantity applied. Five months later, however, these groups had a noticeably darker leaf color than the others, and a month later still this difference was very pronounced.

Since the ammonium sulphate seemed so much more favorable in its effect than the sodium nitrate, it was deemed advisable to divide the group receiving the latter into two groups, one of which received sulphur in the form of flowers of sulphur in January and May, 1923. In the case of the two groups receiving the lighter application of sodium nitrate one application of sulphur was equivalent to the sul-

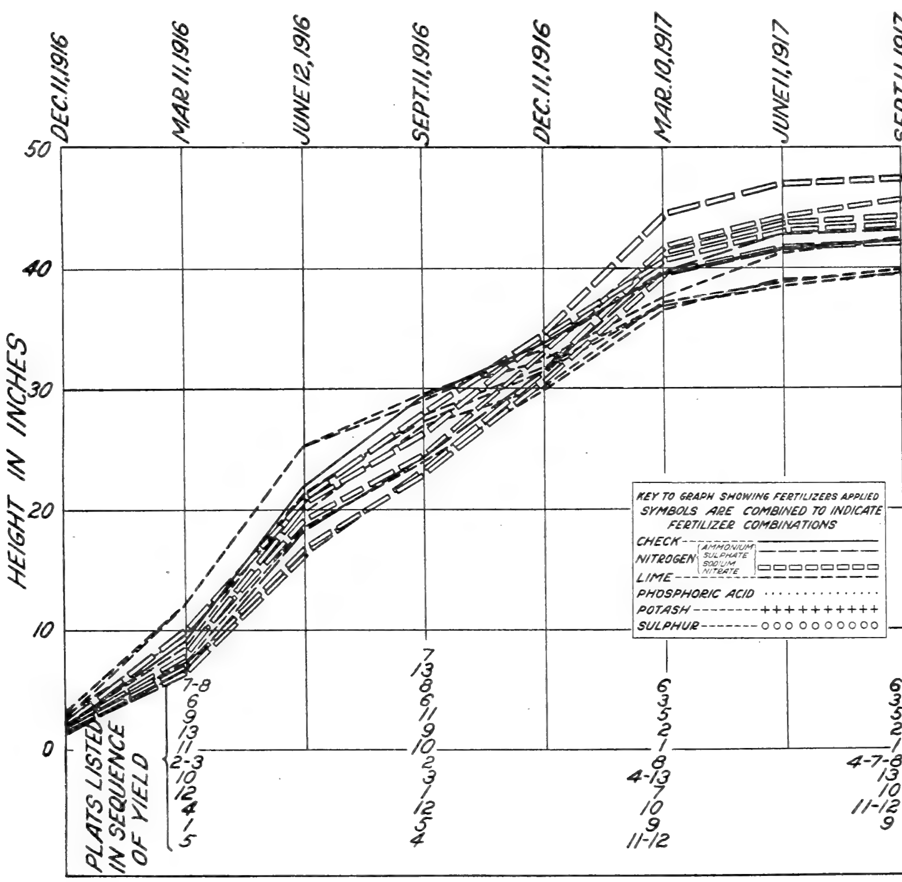


FIG. 15.—Growth of young coffee trees in cans following applications of nitrogen and of lime

phur in 8 grams of ammonium sulphate; and, correspondingly, in the case of those receiving the two heavier applications of sodium nitrate it was equivalent to that in 12 grams of ammonium sulphate. The first application was made when the test was half over, and the total quantity of sulphur applied was less than that carried in the series of ammonium sulphate applications. For this reason it is not deemed necessary to give the matter further consideration than to say that the results were not in agreement, the three groups receiving sulphur being superior to their checks, and the fourth inferior, on the termination of the test in September, 1923. The average superiority of the sulphur-treated plants over the check plants for the whole period was

7 per cent in height, 8 per cent in number of leaves, 6 per cent in weight of leaves, and 7 per cent in weight of trunks and branches. The group receiving the lighter application of ammonium sulphate and that receiving an equivalent quantity of nitrogen in sodium nitrate, and the check were photographed July 27, 1923, by which time the differences due to fertilizer were plainly evident. (Pl. 3.) Figure 16 graphically shows the development of the young trees as

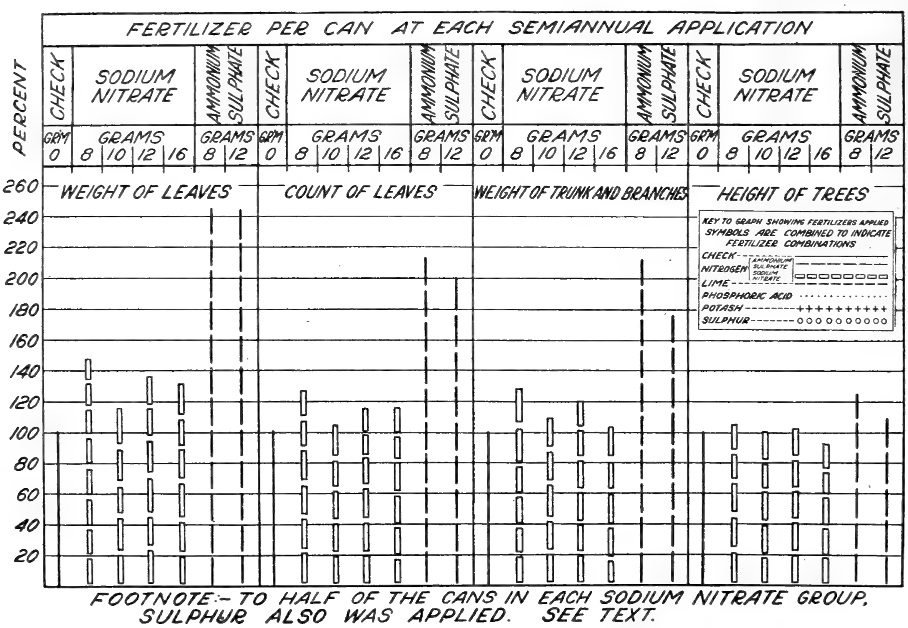


FIG. 16.—Development of young coffee trees as affected by the nitrogen carrier. Data expressed in percentages of the check at close of test, September, 1923

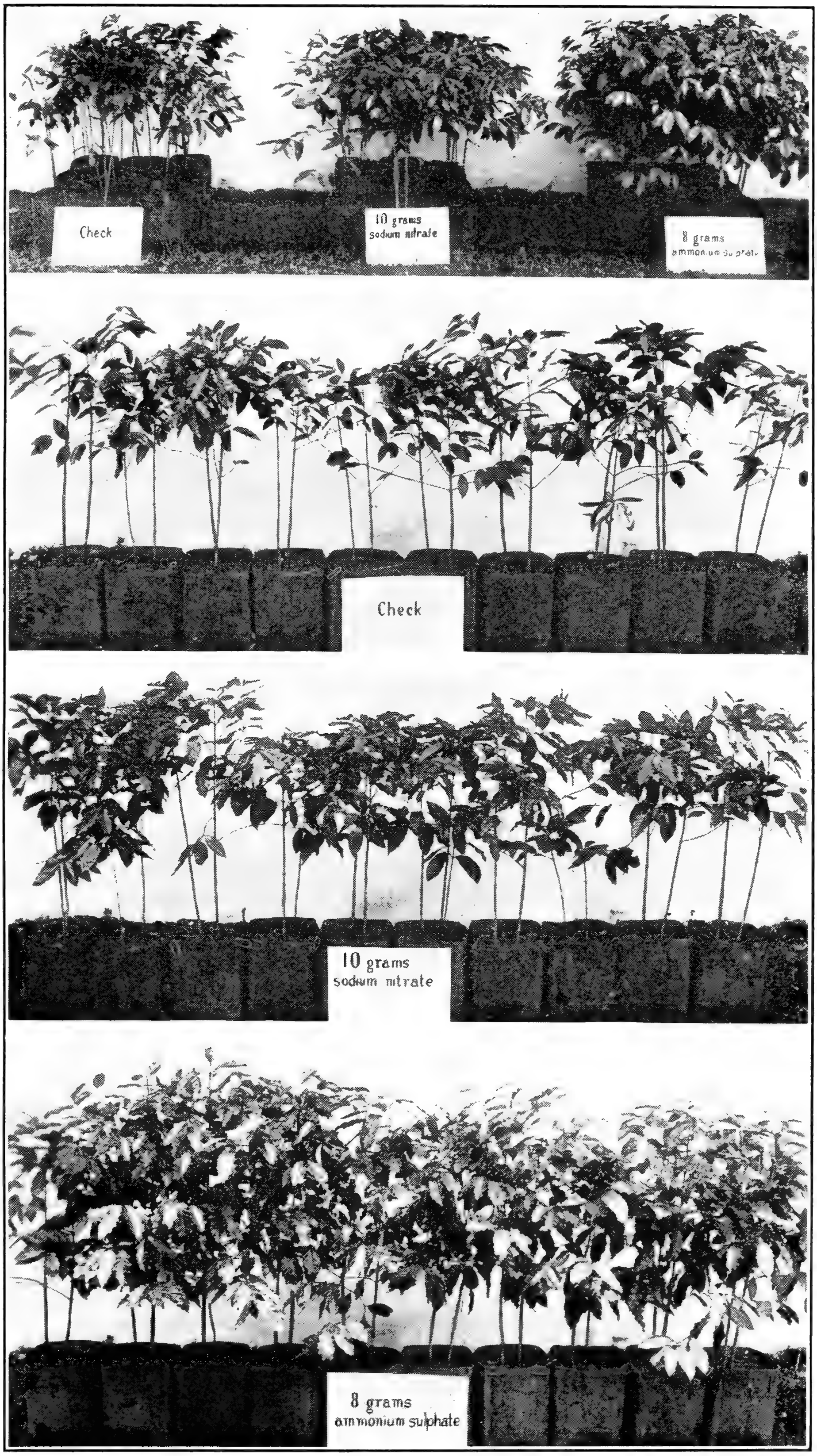
affected by the nitrogen carrier, the data being expressed in percentages of the check. Table 13 shows the leaf growth and weight and woody development above ground resulting from the different forms of nitrogen.

TABLE 13.—*Development of young coffee trees as affected by ammonium sulphate as compared with sodium nitrate*[1]

Fertilizer per can per application	Group [2]	Average height per tree	Average number of leaves	Average weight of leaves	Average weight of trunks and branches
		Inches		*Grams*	*Grams*
Sodium nitrate (8 grams)	1	31	85	57	68
Ammonium sulphate (8 grams)	2	37	142	94	111
Sodium nitrate (10 grams)	3	30	70	44	58
Nothing (check)	4	30	67	38	52
Sodium nitrate (10 grams)	5	30	76	52	63
Ammonium sulphate (12 grams)	6	32	133	93	92
Sodium nitrate (16 grams)	7	27	77	50	54

[1] Data taken at close of the test, September, 1923.
[2] Each group contained 20 trees except Group 6, which had 17, 3 having died.

Some interesting comparisons are furnished. Both ammonium sulphate groups surpassed the check in height, but this was true of only



EFFECT ON GROWTH OF COFFEE SEEDLINGS OF APPLICATIONS OF EQUAL QUANTITIES OF NITROGEN IN AMMONIUM SULPHATE AND SODIUM NITRATE

one sodium nitrate group—that receiving the lightest application. The best foliated sodium nitrate group averaged 23 per cent more than the check in number of leaves per tree, whereas the ammonium sulphate groups surpassed the check by 99 and 112 per cent. In the corresponding leaf weights, the best sodium nitrate group was ahead of the check by 50 per cent, whereas the ammonium sulphate groups surpassed it by 145 and 147 per cent. In weight of woody growth, the best sodium nitrate group was heavier than the check by 31 per cent, whereas the ammonium sulphate groups averaged 77 and 113 per cent heavier than the check. The benefit from ammonium sulphate was most pronounced and that from sodium nitrate decidedly less in comparison.

In another test, begun in 1923 to compare further the effects of ammonium sulphate and sodium nitrate and to show how frequency of application of the latter and the addition of sulphur might affect its action, three series of forty 5-gallon containers were each filled with heavy clay, river loam, and ocean beach sand, respectively. In August, 1923, seed from a single tree of the Padang variety of Arabian coffee was planted, and in November, 1923, three seedlings (later thinned to two) were set in each container. At three weeks after setting, it was observed that many seedlings were damping off badly in the river loam, but that none were so affected in the sand or clay. Numerous seedlings in the loam had, therefore, to be reset.

Each soil group of 40 cans comprised 10 receiving 8 grams of ammonium sulphate semiannually; 20 receiving the same quantity of nitrogen in the form of sodium nitrate (10 in semiannual applications of 10 grams, and 10 in monthly applications of 1.7 grams); and the remaining 10 cans which received no nitrogen. Half the cans in each division, excepting that receiving ammonium sulphate, were given, in the form of flowers of sulphur, semiannual applications of sulphur equal to that carried in 8 grams of ammonium sulphate. The semiannual applications were made from January 3, 1923, to January 3, 1925, inclusive, and the monthly applications from January 3, 1924, to June 3, 1925.

At less than two months after setting, the plants in sand were unsatisfactory in appearance. One month following the first fertilizer application the plants receiving no nitrogen were noticeably very yellow in contrast with the green of all others, including plants receiving sodium nitrate in very small applications. At this time the plants in clay made the best appearance, and those in sand the poorest. At one year after setting, less than 1 plant in 5 of those in sand still retained foliage, and those which had not died had made very little growth. In July, 1925, when the test was brought to a close, all plants in sand, except one were dead. The one exception measured 13½ inches in height, and had only four leaves. Nitrogen and sulphur had proved entirely inadequate for the development of young seedlings in sand.

On account of the widespread disease infection in the loam, which retarded growth or killed many of the trees, the conditions for a study of the comparative effects of fertilizer were much less uniform than was the case with the healthy trees in the clay. Data from trees grown in the loam, although less reliable, show some interesting points of agreement with the former, and are given in Table 14.

TABLE 14.—*Development of young coffee trees as affected by the nitrogen carrier, frequency of application, and sulphur*[1]

Kind of soil	Treatment	Average number of leaves per tree	Average weight of leaves per tree	Average height per tree	Average weight of trunk and branches per tree
			Grams	*Inches*	*Grams*
Clay	Ammonium sulphate, semiannually applied	107.8	67.6	45.8	118.4
	Sodium nitrate, semiannually applied, plus sulphur	99.2	70.6	45.8	118.6
	Sodium nitrate, semiannually applied	81.3	54.8	40.0	80.7
	Sodium nitrate, applied monthly, plus sulphur	116.6	81.4	45.4	127.7
	Sodium nitrate, applied monthly	98.8	65.3	43.4	103.0
	Sulphur	42.1	27.8	35.2	54.8
	Nothing (check)	58.8	36.6	38.2	69.6
Loam	Ammonium sulphate, semiannually applied	56.9	32.9	35.4	86.7
	Sodium nitrate, semiannually applied, plus sulphur	53.3	31.2	32.1	61.8
	Sodium nitrate, semiannually applied	39.6	23.4	30.9	48.0
	Sodium nitrate, applied monthly, plus sulphur	114.9	67.1	39.1	106.9
	Sodium nitrate, applied montlhy	78.6	52.5	39.4	105.1
	Sulphur	19.3	8.9	25.1	20.3
	Nothing (check)	19.6	7.1	23.9	18.9

[1] Data taken at close of the test, July, 1925.

Thirteen of the 80 trees in loam were dead at the close of the test, whereas of those grown in clay 1 was dead, 1 destroyed, and 1 was excluded because of its poor condition unrelated to fertilization. Counts of the leaves per tree were made at quarterly intervals.

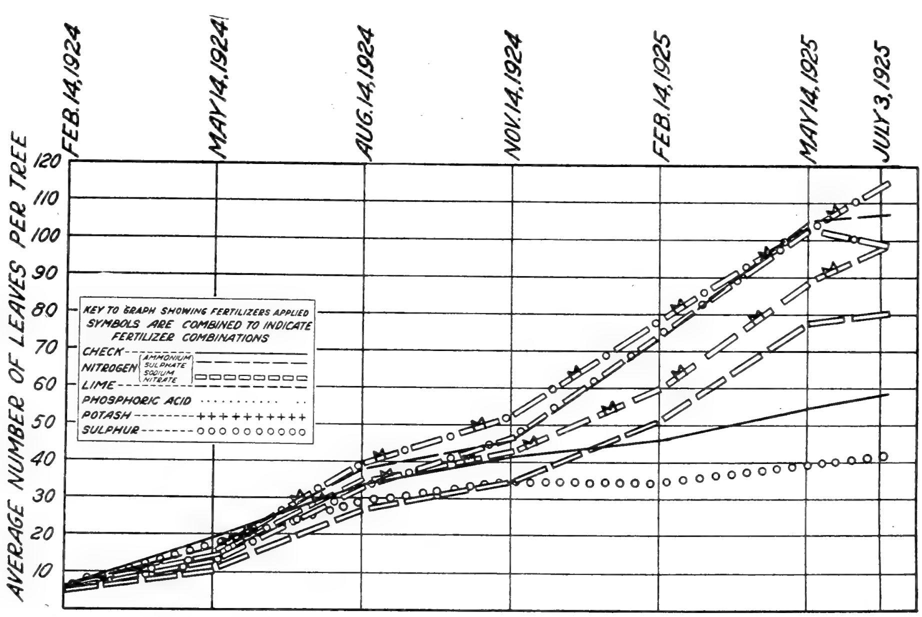


FIG. 17.—Development of leaves on young coffee trees as affected by the nitrogen carrier, frequency of application, and addition of sulphur. M indicates monthly applications of nitrogen. Otherwise, applications were made semiannually

Figure 17 graphically shows the average number of leaves per tree produced in clay soil. The trees showed differences due to fertilizer during the first year, but to a much less pronounced degree than a little later. The curves show that ammonium sulphate and sodium nitrate plus sulphur were very effective in increasing the number of

leaves, and also that sodium nitrate alone applied monthly was much more effective than when applied semiannually.

At 18 months following the first fertilizer application, the leaves were counted and weighed, the heights were measured and trunks cut at the ground, and the woody growth above ground was weighed. Figure 18 graphically shows the development of the young trees in clay, expressed in percentages of the check.

Of the trees grown in clay, the group receiving sodium nitrate monthly and sulphur in addition ranked first in number of leaves and in weight of both leaves and woody growth. In height there was little difference between this group and the two groups receiving ammonium sulphate and sodium nitrate, respectively, in semiannual applications plus sulphur. Considering the data as a whole, it is seen that these two latter groups tied for second place. The group receiving monthly applications of sodium nitrate but no sulphur fell

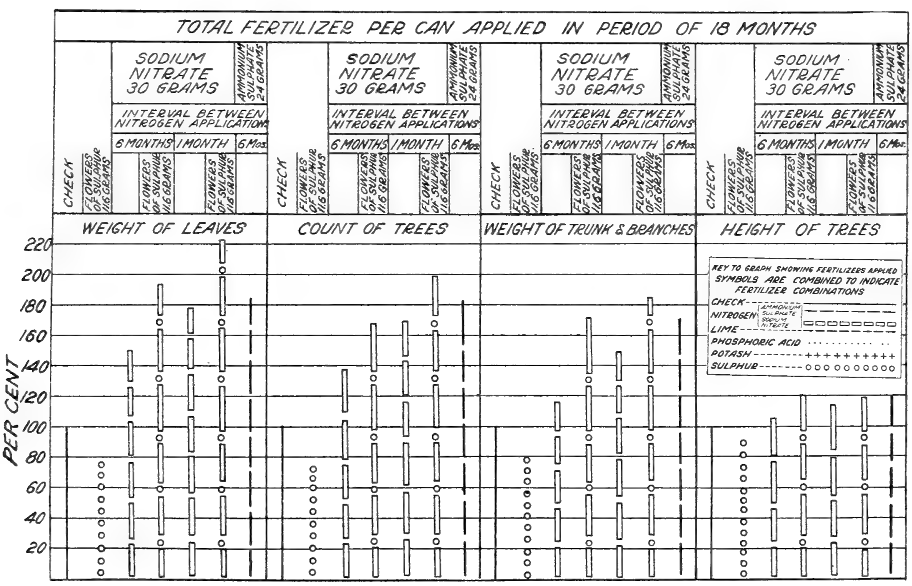


FIG. 18.—Development of young coffee trees as affected by the nitrogen carrier, frequency of application, and addition of sulphur. Data expressed in percentages of the check at close of test, July, 1925

below these three leading groups in weight of both leaves and woody growth and in height, but in every particular it surpassed the group receiving in all an equal quantity of sodium nitrate given in semiannual rather than in monthly applications. The two groups given no nitrogen ranked below all others in every particular, the differences in number and weight of leaves and woody growth being pronounced. The group receiving sulphur alone failed to equal the check, though this fact is presumably without significance.

In both the clay and the loam the group receiving sodium nitrate in monthly applications plus sulphur ranked first. Equal quantities of sodium nitrate proved much more effective in small monthly than in semiannual applications six times as large. The latter proved much less effective than equal quantities of nitrogen in ammonium sulphate. Nitrogen was least effective in semiannual applications of sodium nitrate alone, and all groups given nitrogen grew better than those to which it was not applied.

The results of the test indicate that if sodium nitrate is used as a fertilizer for coffee it should be given in small quantities at short intervals rather than in larger quantities at longer intervals, and also that sulphur should be supplied in addition.

SUMMARY AND SUGGESTIONS

In the experiments reported in this bulletin nitrogen, phosphoric acid, and potash, singly and in combination, were applied to coffee trees through a series of years and their effects on growth and yield noted.

In a planting of 40 small plats the general trend of future performance as affected by fertilization was indicated as early as the first important crop. The production over an 8-year period showed that potash was effective in increasing yield, and that this was true particularly where nitrogen was used in addition to potash. Heavy applications of nitrogen unaccompanied by potash very adversely affected growth and fruiting, whereas the same quantity of nitrogen in conjunction with potash proved beneficial rather than injurious, trees so fertilized developing luxuriant foliage and heavy crops of fruit. The plat ranking first in yield received this fertilizer combination at the maximum rate. Analyses of the soil solution showed this plat to be higher in acidity than any in the field, thus placing coffee among the acid-tolerant crops. Growth and yield failed to show that the addition of phosphoric acid was of benefit. Growth and yield were closely correlated.

In several other series of plats use of complete fertilizer resulted in all cases in moderate to pronounced increase in yield. In one series the yield from the plat receiving complete fertilizer was approximately three times as great as from the check plat for a 13-year period. On this soil all three elements were necessary for maximum yields.

The size of the coffee cherry was observed to be related to the yield, a notable increase in yield being accompanied by a slight reduction in size of cherry. The only observed effect of fertilizer on size was thus indirect.

In field tests nitrogen appeared to increase early production. In various pot tests it greatly stimulated growth, as was shown by a large increase in number of leaves, in weight of foliage, stem, and roots, and in height. Although the number of leaves was increased, no correlation was observed between leaf length and kind of fertilizer applied.

In both field and pot tests ammonium sulphate, applied semiannually, proved much more effective than sodium nitrate in increasing both growth and yield in a planting of Bourbon coffee.

In cooperative experiments with sodium nitrate alone, applied semiannually for two years on one plantation and four on another, no increase in yield attributable to its use was observed. On the latter plantation a change in fertilizer treatment involving the use of ammonium sulphate and sodium nitrate each singly and in complete fertilizer was followed by an increase in the yield of the plats receiving complete fertilizer. The effectiveness of ammonium sulphate alone was less pronounced and no benefit whatever was ob-

served following the continuance of sodium nitrate alone. In pot tests equal quantities of sodium nitrate were much more effective when applied in small monthly rather than in larger semiannual applications, and the addition of sulphur proved beneficial. Monthly applications of sodium nitrate with semiannual applications of sulphur proved more effective than semiannual applications of ammonium sulphate. The latter, however, retained its established position of superiority over sodium nitrate alone in semiannual applications.

Both pot and field tests failed to indicate any benefit from liming.

It is evident that the coffee tree responds to fertilization. On certain soils a large increase in production may be expected to follow the application of suitable chemical fertilizers in sufficient quantity. The need for potash is particularly evident. This is in harmony with analyses of the fruit. Anstead and Pittock[6] state that "when a chemical analysis of parchment coffee, or coffee berries, is critically examined one fact at once strikes one as being prominent. * * * Potash is a dominant factor in the mineral constituents of the coffee bean. This is prominently brought out in the ash analysis where there is more potash than anything else. This being so it is only logical to suppose that a fertilizer containing a preponderance of potash should help the coffee tree to ripen up and hold its crop."

Either ammonium sulphate or sodium nitrate may be used to supply nitrogen, but the employment of the former is preferable, since in a majority of the tests it has clearly demonstrated its superiority over sodium nitrate in semiannual applications.

The heavy clay soils so extensively planted with coffee in Porto Rico are for months at a time washed by heavy and frequent rains. The surface is generally steeply inclined and subject to rapid drainage. Under such conditions it is probable that much of the nitrogen from large semiannual applications of sodium nitrate would be washed away without benefit to the trees to which it was applied.

The beneficial effect of potash and nitrogen in combination has been clearly demonstrated, but the most favorable ratio between the two remains a problem for future investigations. Until further evidence is obtained on this point, it is believed that a fertilizer for coffee should run proportionally high in potash, such, for example, as one obtained by mixing ammonium sulphate and potassium sulphate in equal parts by weight and containing approximately 10 per cent nitrogen and 24 per cent potash. This combination may prove adequate without the addition of phosphoric acid for certain soils. In other cases it may be advisable to include phosphoric acid, adding to the mixture an equal part by weight of superphosphate. It is suggested that each planter who uses chemical fertilizers for his coffee determine the need of his soil for phosphoric acid by applying to experimental plats each of these two mixtures. The plats should preferably be adjacent and as nearly as possible alike in slope, soil, and condition of trees. The fertilizer combination containing only the two elements may be applied at the rate of 300 pounds to the acre, and the other at the rate of 450 pounds.

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[6] ANSTEAD, R. D., and PITTOCK, C. K. THE VARYING COMPOSITION OF THE COFFEE BERRY AT DIFFERENT STAGES OF ITS GROWTH AND ITS RELATION TO THE MANURING OF COFFEE ESTATES. Planters' Chronicle, vol. 8, No. 36, pp. 455, 456. Sept., 1913.

In the absence of definite knowledge as to the best time to apply fertilizer, applications may be made twice annually, the first soon after the termination of the collection of the crop, and prior to the blossoming of the following crop in late November or December, and the second in May or June when the new crop is in process of development. The fertilizer should be well distributed over the range of the coffee roots and incorporated with the surface soil.

Whether the application of chemical fertilizers to coffee will prove a profitable practice must depend upon the relation between cost of fertilizer and selling price of coffee. Within the period covered by the tests here reported the prices of both varied greatly. With high prices of coffee, use of fertilizers may prove profitable, and conversely, with low prices it may entail a loss.

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